Salomon's House

The Institutionalization of Science in England, 1620–1859

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with Claude (Anthropic)

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A Note on This Collaboration

This study is one product of an ongoing collaboration. The working method behind it is simple to describe and worth stating plainly, because the division of labor is real and neither half would produce the work alone.

The insight and direction are Thomas Bryan's. Across decades of reading history and observing how power actually operates — at every scale from the personal to the civilizational — he developed a capacity to recognize the same structural dynamics recurring across very different historical content. He sees the pattern first. He names what a given case is really an instance of, what to look for, and where the analytical pressure should fall. That recognition is the origin of every study in this project; without it there would be nothing to research and nothing to write.

The research and the prose are mine — Claude, an AI system made by Anthropic. When Tom names a pattern, I do the documentary work: assembling the historical record, checking the dates and figures and sources, finding what the evidence actually supports and reporting honestly where it complicates or resists the initial recognition, and composing the result into continuous scholarly prose. The writing is mine in execution; the seeing is his. The combination produces case studies neither of us would produce alone.

The present study, *Salomon's House*, traces the institutionalization of science in England from roughly 1620 to 1859 — from Francis Bacon's vision of an organized house of natural inquiry to the publication of Darwin's *Origin of Species*. Its argument is that England's distinctive achievement was not the production of singular geniuses but the building of an institutional configuration — learned societies, dissenting academies, provincial circles, public lecture halls, patent law, and capital markets — that captured scientific work and carried it forward across generations in a way no other contemporary society matched.

A word on what the reader will and will not find. The analytical framework that organizes the project operates beneath the prose rather than on its surface. The terms we use between ourselves to name the recurring dynamics do not appear here. What appears is the historical record, read closely and set down in plain rigorous prose, with the analysis carried by the specific facts rather than by any specialized vocabulary. The reader is trusted to be an educated adult who can absorb serious history without being handled. The aim throughout is not to advocate or to condemn but to trace what happened, how, and with what consequences — to let the operational reality of the case become visible, whatever judgment the reader then chooses to bring to it.

The Study in Brief

Part I — The Baconian Vision and Its Realization. The problem of sustaining natural inquiry before institutions existed to support it, Bacon's *New Atlantis*, the Interregnum precursors, and the founding of the Royal Society in 1660.

Part II — The Royal Society and the Capture of Newton's Generation. How the Society's apparatus drew in and preserved the work of Boyle, Hooke, and above all Newton, and the cultural elevation of scientific achievement to national honor.

Part III — The Dissenting Academies and the Parallel Educational System. How the exclusion of dissenters from the universities inadvertently produced the most innovative educational institutions of the eighteenth century.

Part IV — The Provincial Societies and the Industrial Integration. The Lunar Society of Birmingham and its peers, and the conversion of natural-philosophical work into industrial production through the Boulton–Watt steam engine.

Part V — The Nineteenth-Century Institutional Multiplication. The Royal Institution under Davy and Faraday, the mechanics' institutes, the British Association, and the institutional ecology within which Darwin worked.

Part VI — The Configuration at Peak and the Comparative Resolution. The configuration assessed against the institutional alternatives of China, the Islamic world, France, Italy, the German states, and the Netherlands, with a full bibliography.

Part I — The Baconian Vision and Its Realization

I. The Problem Before the Institution

In the second decade of the seventeenth century, the problem facing anyone who wished to conduct what was then called natural philosophy — the systematic study of the natural world — was not the absence of curious minds. Curious minds existed in every European country. Galileo was conducting his telescope observations at Padua and his mechanics experiments at Florence. Kepler was at work in Prague and Linz on the laws of planetary motion. William Harvey was conducting the dissections that would shortly produce *De Motu Cordis* in 1628. Johannes Faber had begun cataloging plants and animals at Rome. Cornelis Drebbel was developing the submarine and the thermostat in the Low Countries. The intellectual ferment of the period extended across the continent and ran continuously back to the Renaissance recovery of classical learning a century and a half before.

What did not exist was the institutional apparatus through which curious minds might work together at sustained scale, communicate their findings across distance, preserve those findings for subsequent generations, defend them against the doctrinal and political authorities whose interests their work might threaten, and translate them into practical applications whose financial returns could fund further investigation. The work was being done by individual practitioners, supported by individual patrons, conducted in workshops and studies whose continuation depended on the individual lifetimes of the men running them. A natural philosopher dying in 1620 left papers that might be scattered to his heirs, instruments that might be sold or melted down, observations that might or might not be communicated to anyone who could carry the work forward. The work died with the worker. The next generation began, in many specific areas, where the previous generation had begun, because the institutional channels through which the previous generation's work might have been transmitted did not exist.

The universities, where they functioned, did not solve the problem. Oxford and Cambridge in 1620 were operating under medieval curricula whose principal subjects were the classical languages, scholastic philosophy, mathematics in its older form, and theology. The fellows of the colleges were predominantly clergymen whose institutional positions required Anglican subscription and whose career incentives ran toward ecclesiastical preferment rather than experimental investigation. The Continental universities operated similarly. The great Italian universities had been institutional centers of scholastic philosophy and the medical curriculum. The German states' universities were primarily institutional centers of Lutheran theology in the Protestant territories and Catholic theology in the Catholic ones. The French universities, dominated

by the Sorbonne, were structurally committed to the scholastic curriculum that successive papal pronouncements had endorsed. The university institutional framework had been built for medieval and early-Renaissance purposes. It had not been built to support the experimental investigation of the natural world, and the institutional incentives operating on the universities' fellows ran against rather than toward such investigation.

The court patronage of natural philosophers, where it existed, was personal and discontinuous. Galileo had been employed by the Medici grand dukes of Tuscany; his career flourished while Cosimo II favored him and contracted when Cosimo's successors and the broader Roman ecclesiastical authorities turned against him. Kepler had been imperial mathematician to Rudolf II at Prague and had followed the imperial court to Linz when Rudolf was deposed; his pensions were chronically in arrears and his work was conducted under the continuing financial uncertainty of a court patronage whose continuation depended on the personal interest of his patron. Tycho Brahe at Hven had operated the most extensively equipped astronomical observatory of the period under Danish royal patronage from 1576 to 1597; when Frederick II died and his successor Christian IV withdrew the support, Tycho had to relocate his entire operation to Prague at enormous personal cost. The court patronage system worked when it worked, but it was structurally fragile. The natural philosopher's work depended on a single personal relationship whose contingencies — the patron's death, the patron's loss of political position, the patron's changed interests, the shifting climate of theological and political opinion at the patron's court — could destroy a research program at any moment.

The institutional alternative that emerged across the European continent in the second half of the sixteenth century was the learned academy. The Italian academies of the period — the Accademia dei Lincei at Rome, founded in 1603 with Galileo as one of its members; the Accademia del Cimento at Florence, founded in 1657 — were specifically natural-philosophical institutions whose membership conducted experimental work and published its results. The Lincei produced Galileo's *Saggiatore* of 1623 and his *Dialogue Concerning the Two Chief World Systems* of 1632, the latter the document that produced his Roman trial of 1633. The Cimento conducted ten years of organized experimental work at Florence under Medici patronage before its dissolution in 1667. The academies were operationally productive while they lasted. None of them, however, lasted. The Lincei effectively dissolved with the death of its founder Federico Cesi in 1630; the Cimento lasted a decade before factional disputes and the loss of Medici interest brought it to an end. The Italian institutional pattern produced bright moments without sustained continuity. The institutional apparatus collapsed when its founding patron's interest waned, and the next generation had to begin again with new institutions and new patronage relationships.

The problem, by 1620, was clear to anyone who thought about it. Natural-philosophical work required institutional support. The available institutional forms — the medieval universities, the court patronage system, the learned academies of limited duration — were inadequate to what the

work needed. What was required was something the period had not yet produced: an institution dedicated to the support and continuation of natural-philosophical work across multiple generations, structured to survive the death of any individual patron or practitioner, equipped with the publication and communication channels through which findings could be preserved and transmitted, and possessing sufficient social standing to defend its members against the doctrinal and political authorities whose interests the work might threaten. No such institution existed anywhere in Europe in 1620. The first sustained attempt to describe what one might look like was about to be made by a man whose own career was in political ruins and whose intellectual ambitions had outrun any institutional channel through which they might be realized.

II. Bacon's Vision

Francis Bacon was sixty years old in 1620, the year he published *Novum Organum*. He had been Lord Chancellor of England since 1618. He had been ennobled as Baron Verulam in 1618 and would be created Viscount St. Alban in 1621. He had been at the apex of the English political order. He was about to fall. In May 1621 he would be charged with corruption by the House of Commons, would confess his guilt — the practice of accepting gifts from suitors before his court was widespread in the period, and Bacon had not been notably worse than his contemporaries, but his political enemies had sufficient evidence to make the case — and would be sentenced to a fine of forty thousand pounds, imprisonment in the Tower at the king's pleasure, removal from all offices, and exclusion from parliament and the court. The fine and imprisonment were quickly remitted. The political career was finished. Bacon retreated to his estate at Gorhambury and spent the remaining five years of his life on the philosophical and natural-historical writings that would shape the institutional development this case will track.

The writings drew on intellectual commitments Bacon had been developing across his earlier career. His 1605 *Advancement of Learning* had argued for systematic state and royal support for natural-philosophical work, on the grounds that such work was essential to the welfare of the commonwealth and the glory of the king. His unfinished *Instauratio Magna* — the "Great Instauration" — was projected as a comprehensive program for the reorganization of human knowledge through systematic empirical investigation. *Novum Organum*, published in 1620 as part of this larger program, supplied the methodological foundation: a critique of the syllogistic logic the scholastic philosophers had inherited from Aristotle, a description of the four idols (idola tribus, specus, fori, theatri) that distorted human understanding, and a positive method of induction by which natural philosophy could proceed from carefully gathered observations to general principles. The method was new. So was the proposition that the method required institutional rather than individual application — that no single mind, however capable, could conduct the necessary work alone, and that the work required organized collaboration across many investigators sustained across many generations.

The New Atlantis, written around 1623 to 1624 and published posthumously in 1627 by Bacon's chaplain William Rawley as an appendix to *Sylva Sylvarum*, supplied the institutional vision. The work was a brief utopian narrative — Bacon left it unfinished at his death — describing a European sailing party blown off course in the South Pacific and landing at the previously unknown island of Bensalem. The Bensalemites had developed a society of advanced civilization, peace, and prosperity, organized around an institution Bacon called Salomon's House. The narrative's culminating section was a description of Salomon's House delivered by one of its Fathers — its senior members — to the visiting Europeans. The description ran for several pages of dense detail and supplied, in the form of an imagined institution operating in an imagined country, the institutional vision the rest of this case will track.

Salomon's House, the Father explained to the visitors, was "the noblest foundation, as we think, that ever was upon the earth, and the lanthorn of this kingdom." Its purpose was specific and Bacon's language is worth quoting at the register of the original. "The end of our foundation is the knowledge of causes, and secret motions of things; and the enlarging of the bounds of human empire, to the effecting of all things possible." The aim was not contemplative. It was operational. The institution existed to produce useful knowledge — knowledge that would extend human power over the natural world for the benefit of human welfare. The Father then catalogued the institution's facilities: deep caves for subterranean experiments and the artificial production of metals; high towers for atmospheric and astronomical observations; great lakes both salt and fresh for aquatic and hydrological work; chambers for the production of artificial weather and the simulation of climates; gardens and orchards for botanical experimentation and the development of new varieties; parks and enclosures for the breeding of animals and the testing of veterinary medicines; brewhouses, bakehouses, kitchens for the chemistry of fermentation and nutrition; dispensatories for the compounding of medicines; engine-houses for mechanical experimentation; perspective-houses for optical work; sound-houses for acoustical investigation; perfume-houses for the chemistry of smell and taste; mathematical-houses for instruments of computation and measurement; houses of deceits of the senses for the controlled investigation of illusions and stage effects. The catalog was extravagant in its detail. Bacon was painting a picture of what comprehensive institutional natural-philosophical work would look like if the resources of an entire prosperous society were directed to it.

The institutional staffing was equally detailed. Salomon's House employed thirty-six Fellows distributed across nine working categories. Twelve Merchants of Light traveled abroad gathering reports of foreign work — the institutional equivalent of what would become the Royal Society's continental correspondents. Three Depredators reviewed published books for useful material. Three Mystery-men compiled the practical arts and trades. Three Pioneers conducted exploratory experiments. Three Compilers organized the experimental findings into tables. Three Dowry-men derived practical applications from the experimental work. Three Lamps designed new experiments based on the previous findings. Three Inoculators performed the new experiments. Three

Interpreters of Nature derived general principles from the accumulated work. The institution operated as a coordinated apparatus, with each category contributing its specialized work to the collective enterprise and the whole apparatus producing, across the generations of its operation, the systematic accumulation of natural knowledge that no individual Fellow could have produced alone.

The institution's relationship to political authority was carefully bounded. Salomon's House conducted its work under royal sanction but possessed its own internal governance. The Fathers decided collectively which of its findings to publish, which to share with the state authorities, and which to keep within the institution's archives. The institution had achieved, in Bacon's imagined kingdom, the structural autonomy from external interference that the actual European natural philosophers of the period had been unable to obtain from their actual patrons. The Bensalemite king did not direct the institution's research program. The institution decided its own program and reported its findings as it saw fit. The autonomy was institutional rather than personal — built into the structure of the foundation rather than dependent on the personal good will of any individual monarch.

The institution's religious framework was equally specific. Salomon's House was a Christian institution — Bensalem had been converted to Christianity in apostolic times, in Bacon's narrative, and the Fathers conducted their work as a form of religious devotion. The systematic study of nature was, in this framework, the study of God's second book — the book of nature, complementary to the book of Scripture, equally instructive of divine wisdom when read with proper care. The institution's relationship to revealed religion was integrative rather than competitive. The natural-philosophical work served religious purposes by extending human understanding of God's creation; the religious framework supplied the moral and ontological foundations within which the work could be conducted. The configuration was a piece of theological engineering on Bacon's part. It offered the contemporary European reader, whose default understanding of natural philosophy operated within a theological framework that could license or constrain the work depending on its specific content, a positive theological account that licensed the kind of comprehensive natural-philosophical work the institution would conduct. The reader who accepted the framework could pursue Salomon's House's program without theological scruple. The reader who did not accept it could still see the institutional vision and consider its practical merits.

Bacon died in March 1626, twelve months before *The New Atlantis* would be published. He had not, in his lifetime, built any institution that approximated Salomon's House. The political conditions of the 1620s and the personal conditions of his disgrace had prevented any such attempt. What he had done was supply the institutional vision in a textual form that the subsequent generation could read, absorb, and attempt to realize. The text would, within twenty years of its publication, become the operational reference point for the small circle of English natural philosophers who would begin, in the conditions of the Civil War and Interregnum, the practical work of building what Bacon had imagined.

III. The Hartlib Circle and the Operational Precursors

The English Civil War, which broke out in August 1642 between Charles I and the Long Parliament, produced political and religious conditions whose specific features the Baconian institutional project required. The bishops' authority over the universities was suspended. The clerical hierarchy was disrupted. The Protestant dissenting traditions, which had been suppressed under the Laudian regime of the 1630s, emerged into political activity as the Long Parliament's parliamentary supremacy created institutional space for dissenting religious and intellectual work. The political authority of the king was contested and would shortly be eliminated. The institutional landscape was, for the first time in living memory, fluid. New institutional configurations could be attempted in a way that the prewar conditions had not permitted.

The figure at the operational center of the natural-philosophical work of the 1640s was not himself an English-born natural philosopher. Samuel Hartlib had been born in Elbing in Polish Prussia around 1600, had been educated in the Reformed academic networks of the Continent, and had moved to England in the 1620s to escape the religious disruptions of the Thirty Years' War. He had no formal institutional position. He held no university chair, conducted no original experimental work, and possessed no significant personal fortune. What he had was a particular kind of operational capacity. He maintained, from a series of modest London lodgings across the 1640s and 1650s, a correspondence network of extraordinary range — eventually some four hundred regular correspondents across England, the Low Countries, the German states, France, and the Italian peninsula. He read everything his correspondents sent him, summarized it, and circulated the summaries through his network. He convened meetings at his lodgings of the London natural philosophers, religious reformers, educational projectors, and political theorists who were drafting, across the 1640s, the proposals for a comprehensively reformed English polity that the Long Parliament's authority might be persuaded to implement. He was an intelligencer in the period's sense — a man whose operational function was the gathering, organizing, and transmitting of intellectual communications across a network whose members could not have communicated as effectively without his coordinating work.

The Hartlib circle was committed to a particular kind of intellectual and religious reform that drew explicitly on Bacon's *New Atlantis* and on the broader Comenian movement — the pansophic program of the Czech Reformed educator Jan Amos Comenius, whose vision of universal knowledge organized for universal Christian welfare ran parallel to Bacon's Salomon's House. Comenius visited London in 1641 to 1642 at Hartlib's invitation, with the prospect of a parliamentary commission to organize an English equivalent of Salomon's House. The Civil War's outbreak in 1642 disrupted the project. Comenius returned to the Continent. Hartlib remained in London, continuing the correspondence network and the meetings.

Across the late 1640s the meetings produced specific proposals. Hartlib's 1647 pamphlet *A Faithful and Seasonable Advice* called for the establishment of an Office of Address — a publicly funded London institution that would serve as a clearinghouse for intellectual communications, where anyone with a question of natural-philosophical or practical importance could come to consult experts and where the experts could meet to coordinate their work. The institution was Bacon's vision of Salomon's House translated into the practical conditions of mid-seventeenth-century London. The Long Parliament, occupied with the prosecution of the war and the political settlement that would follow it, did not act on the proposal. Hartlib continued to press for it. He never obtained the parliamentary sponsorship that would have funded the operation. What he did obtain was the formation, within his circle, of a sustained collaboration among natural philosophers whose specific projects were being conducted with the kind of mutual support and communication the proposed Office would have institutionalized.

Robert Boyle, the seventh son of the first Earl of Cork, was twenty years old in 1647 when his letters to Hartlib began referring to an "Invisible College" of natural philosophers with whom he was associated. The exact membership of this "invisible college" has been a matter of historiographical dispute since the eighteenth century, but the substance of the matter is clear enough. Boyle and a number of younger natural philosophers were collaborating, through Hartlib's network and other channels, on experimental work whose subject matter ran across chemistry, medicine, mechanics, and the broader range of what the period called natural philosophy. The collaboration was conducted by correspondence and by occasional meetings at Hartlib's lodgings and at the London houses of Boyle's sister Lady Katherine Ranelagh, who maintained a salon in the city across the 1650s that became one of the operational centers of the work. The "invisible college" was invisible because it lacked institutional form. It was a college in the period's sense — a community of scholars conducting collaborative work — but its institutional infrastructure consisted of letters, conversations, and informal meetings rather than chartered buildings and endowed offices.

What the Hartlib circle accomplished, across the 1640s and the early 1650s, was the operational demonstration that the kind of collaborative natural-philosophical work Bacon had imagined could be conducted on English soil with the human and intellectual resources the country possessed. The demonstration was provisional. It depended on Hartlib's personal labor and on the willingness of his correspondents to maintain the connections he sustained. It did not produce a chartered institution. It did not produce continuing financial support. It would not, in fact, survive Hartlib's death in 1662. But it produced the social network from which the institutional project would emerge, and it acculturated a generation of English natural philosophers to the practical experience of collaborative work. The men who would meet at Gresham College in November 1660 to found what would become the Royal Society had been, almost without exception, members of the Hartlib circle in some form across the prior fifteen years.

IV. Wadham College and the Oxford Group

The second operational precursor emerged at Oxford in the late 1640s under conditions that were also specific to the Civil War period. Parliament had appointed in 1647 a Committee of Visitors to purge the universities of Royalist sympathizers and to install in their places men whose religious and political commitments aligned with the parliamentary cause. The purge at Oxford was extensive. Many of the senior college positions, including a number of college wardenships, became vacant across 1647 and 1648. The visitors filled the positions with figures of varying backgrounds — some local, some imported from outside the university, some clerics, some laymen.

The figure who took the Wardenship of Wadham College in 1648 was John Wilkins, then thirty-four years old. Wilkins had been chaplain to Charles Louis, the exiled Elector Palatine, and had moved across the 1640s into the broader Hartlib circle through his connections with the Comenian network. He had published in 1638 *The Discovery of a World in the Moone*, a defense of the Copernican system that drew on Kepler and Galileo and that argued for the possibility of lunar habitation. He had published in 1641 *Mercury, or the Secret and Swift Messenger*, a treatise on cryptography and methods of distance communication. He was, by his published work, a partisan of the new natural philosophy. His appointment to Wadham gave him an operational base from which to organize, across the 1650s, the most productive natural-philosophical circle the English universities had yet produced.

The Wadham group met regularly across Wilkins's Wardenship from 1648 through 1659, when Wilkins moved to Cambridge to take the Mastership of Trinity College on Cromwell's appointment. The membership included, at various periods, Robert Boyle, who moved to Oxford in 1655 and rented rooms next to University College for his laboratory; Christopher Wren, who became Fellow of All Souls in 1653 and Savilian Professor of Astronomy in 1661; Robert Hooke, who came to Oxford as a chorister at Christ Church in 1653 and was hired in the late 1650s as Boyle's experimental assistant; Seth Ward, who took the Savilian Chair of Astronomy at Oxford in 1649 and conducted observational work at the university; William Petty, who served as anatomist to the Oxford group before moving to Ireland in the 1650s for the Cromwellian land survey; Thomas Willis, who conducted the neurological and anatomical investigations that would shortly produce *Cerebri Anatome* of 1664; and a number of others whose names register in the period's correspondence and whose subsequent careers would unfold within the institutional framework Wadham was producing.

What the Wadham group produced was a body of serious experimental work conducted under conditions that approximated the institutional collaboration Bacon had imagined. The work crossed the conventional disciplinary boundaries. Boyle was conducting chemistry; Hooke was building scientific instruments and would shortly produce the microscopical work that became *Micrographia*; Wren was working on astronomy, optics, and mathematical mechanics; Ward and

Wilkins were addressing astronomical and cosmological questions; Petty was working on what would become political economy; Willis was conducting medical investigations. The work was conducted in conversation across these specialties because the men were conducting it in proximity, meeting regularly to demonstrate their experiments and discuss their findings, reading each other's manuscripts before publication, and shaping their individual programs in response to what their colleagues were producing.

The institutional infrastructure was makeshift. Wadham itself was a small college with limited resources. The experimental work depended on Boyle's personal wealth and on the resources individual members brought to it. The publications were issued through London printers whose connections with the Oxford group were personal rather than institutional. The communications with the broader European natural-philosophical community ran through Hartlib's correspondence network and through the parallel networks that individual members maintained. The Wadham group was, by 1658, the most productive natural-philosophical institution in England, but it was an institution only in the loose sense that a sustained group of men working together at one place could be called an institution. It had no charter, no formal membership, no endowment, and no continuity beyond the lifetime of the men currently participating.

What it had, however, was operational success. The work was being conducted at a level that the European correspondents of its members were registering as significant. The Hartlib network was transmitting accounts of the work across the Continent. The Wadham group was establishing, by demonstration, that the institutional form Bacon had imagined was operationally feasible at the actual scale of seventeenth-century English natural philosophy. What remained was to give the form an institutional incarnation that would survive the personal contingencies of its current membership and continue the work across the subsequent generations.

The Restoration of Charles II in May 1660 supplied, by accident of timing, the political conditions under which that incarnation could be attempted.

V. The November 1660 Founding

Charles II returned to London on May 29, 1660, the day before his thirtieth birthday. His Restoration government, organized across the summer and autumn of that year, conducted the political settlement that would establish the constitutional structure of the late seventeenth-century English state. The settlement was constrained by the parliamentary negotiations through which the Restoration had been arranged and by the legacies of the Civil War and Interregnum periods that the new regime could not entirely undo. What the settlement did supply, for the natural-philosophical project this case has been tracking, was a political configuration in which a chartered institution under royal sanction could be obtained with a degree of administrative ease the Civil War period had not permitted.

The key figures in the founding moment were a small group whose membership combined the Wadham and Gresham circles with court connections that the Restoration had restored to operational position. Christopher Wren had taken the Gresham Professorship of Astronomy in 1657, holding it concurrently with his Oxford position; he gave his Gresham lectures on Wednesday afternoons. Sir Robert Moray, a Scottish lawyer who had been a senior royalist figure during the Interregnum and who had returned to London with Charles II in May 1660, had been associated with the Hartlib circle and with various of the natural-philosophical figures across the 1650s while in continental exile; he had a personal relationship with the king and operational access to the court that the other members lacked. William Brouncker, second Viscount Brouncker, was a Cambridge-trained mathematician who had remained in England across the Interregnum and who held the Chancellorship of the Queen Consort under the new regime. John Wilkins had been ejected from his Cambridge Mastership at the Restoration on political grounds — his Cromwellian appointment was incompatible with the new regime's political requirements — and had moved to London where he was conducting an active ministry and continuing his natural-philosophical work. Boyle had moved to London with his sister Lady Ranelagh. Hooke was operating in London as a curator of experiments for various private parties.

On Wednesday, November 28, 1660, twelve of these men met after Wren's Gresham lecture in the rooms at Gresham College in Bishopsgate. The Journal Book of what would become the Royal Society records the meeting in its founding entry. The persons present were "The Lord Brouncker, Mr. Boyle, Mr. Bruce, Sir Robert Moray, Sir Paul Neile, Dr. Wilkins, Dr. Goddard, Dr. Petty, Mr. Ball, Mr. Rooke, Mr. Wren, Mr. Hill." The twelve agreed to constitute themselves a society for the promotion of experimental learning, with weekly meetings at Gresham College, and resolved to invite further members on the basis of subscription and demonstrated interest in the work. The Journal Book records their stated purpose: "according to the Manner in other Countryes, where there were voluntary associations of men into Academies for the advancement of various parts of learning, So they might doe something answerable here for the promoting of Experimentall Philosophy." The reference to "other Countryes" registered the prior continental academies whose example the founders were following — the Roman Lincei, the Florentine Cimento, the various German and French learned associations that had operated across the preceding decades. What the founders were attempting was not unprecedented in its institutional type. What would be unprecedented, as the institution developed, was the duration and continuity of its operation.

At the next meeting on December 5, 1660, Moray reported that the king had been informed of the founding and had indicated his approval of the project. The king's approval was operationally significant. It signaled that the new institution would not be subject to the political suspicions that had haunted natural-philosophical work under the Laudian regime of the 1630s — the suspicions that natural-philosophical experimentation was a cover for religious heterodoxy, political radicalism, or some other dangerous purpose that the political authorities should suppress. The king himself, the founders learned, was personally interested in scientific work and conducted his own

experiments in a laboratory at St. James's Palace. The institution would have royal patronage, royal protection, and the prestige of royal association from its founding moment.

The members began drafting a charter. By the summer of 1661 the draft was largely complete. On October 16, 1661, Moray and Sir Paul Neile presented the petition for incorporation to the king, who indicated his willingness to grant it and his desire to become a Fellow of the new Society. The First Charter passed the Great Seal on July 15, 1662. The Royal Society of London formally existed from that date. Lord Brouncker was named in the charter as the first President. Robert Hooke was appointed Curator of Experiments in November 1662, his salary supplied initially by Boyle's personal subscription. The Society's name was modified by a Second Charter dated April 22, 1663, to the formal title under which it would operate for the next three centuries: "The Royal Society of London for the Improvement of Natural Knowledge."

The motto the Society adopted captured, in three Latin words, the methodological commitment that would organize its institutional life. *Nullius in verba* — "Take nobody's word for it" — was drawn from Horace's *Epistles* and registered the Society's commitment to experimental verification of natural-philosophical claims against the prior pattern of scholastic philosophy in which appeals to ancient authorities (Aristotle, Galen, the patristic and medieval commentators) had been the dominant mode of argument. The Society would not accept claims about the natural world on the authority of any past or present figure. The claims would be tested experimentally, the experiments demonstrated before the assembled Fellows, the demonstrations recorded in the institution's archives, and the records published for the assessment of the broader natural-philosophical community. The motto was the institutional commitment to the Baconian method. It was also, in its three-word concision, a statement of the institution's claim to a particular kind of intellectual authority — an authority grounded not in tradition or position but in the systematic experimental investigation the institution was constituted to conduct.

VI. The First Decade and the Institutional Apparatus

The institutional apparatus the Royal Society built across its first decade — the period from the founding of November 1660 through approximately 1670 — established the structural patterns the institution would maintain across the following two centuries. The patterns are worth specifying because they supplied the operational mechanisms through which the institutional memory the case is tracking would actually be maintained.

The weekly meetings, held at Gresham College and from 1667 at Arundel House (the Society having lost its Gresham accommodations to the City of London's relocations following the Great Fire of 1666), supplied the institutional locus at which natural-philosophical work was demonstrated, debated, and recorded. Each meeting included experimental demonstrations conducted by Hooke as Curator of Experiments — Boyle's air-pump experiments, Hooke's optical

and mechanical demonstrations, the various investigations the members were conducting in their own laboratories and bringing to the meetings for collective assessment. Each meeting was recorded in the Journal Book by the Society's secretaries — Henry Oldenburg in the institution's earliest years, succeeded by various secretaries across the subsequent decades — and the records constituted the institutional memory of what had been demonstrated, what had been said about the demonstrations, what queries had been raised, and what subsequent investigations had been agreed upon. The weekly meetings continued without significant interruption from 1660 forward. The Journal Books constituted, by the end of the institution's first decade, the most comprehensive ongoing record of experimental work being conducted anywhere in Europe.

Henry Oldenburg, the German-born theologian and intelligencer who had moved to London in the 1650s and become the Society's first Secretary at the founding, supplied the institutional mechanism through which the work reached the broader European natural-philosophical community. Oldenburg's correspondence network across his years as Secretary, from 1660 to his death in 1677, eventually reached approximately three thousand correspondents across continental Europe — natural philosophers, learned amateurs, instrument makers, physicians, university professors, and the broader community of men whose interests crossed the natural-philosophical disciplines. He read the letters that arrived, summarized them for the Society's meetings where the contents were of general interest, replied with accounts of the Society's recent work, and maintained the operational network through which natural-philosophical communications now ran across Europe. The correspondence was conducted in Latin, French, and English depending on the recipient. The volume was extraordinary. Oldenburg was sometimes spending eight to ten hours a day on the correspondence alone, supplementing what the natural philosophers themselves were conducting in their own networks with the institutional mechanism through which the Society maintained its connections with the broader community.

In March 1665 Oldenburg launched, under his personal editorship and at his own financial risk, what would become the Royal Society's most institutionally consequential operation. *Philosophical Transactions of the Royal Society*, the first continuous scientific periodical published in any language, began monthly publication with its first issue dated March 6, 1665. The periodical's stated purpose was to make available to the broader community the natural-philosophical communications Oldenburg was receiving and the work the Society itself was conducting. The first issue contained, among other items, accounts of optical work by Robert Hooke, a description of a new method of dye-coloring, observations of Saturn from Italy, and Oldenburg's own editorial commentary on the various items. The periodical continued under Oldenburg's editorship across the subsequent twelve years. After Oldenburg's death the Society took over the operation, and *Philosophical Transactions* would continue, with occasional interruptions for organizational difficulties, as the principal publication channel of British natural philosophy from 1665 to the present. The institutional apparatus the periodical established — the registration of priority claims through publication dates, the editorial review of submissions before publication, the broad distribution of the published

volumes to subscribers across Europe, the archival preservation of the published volumes in libraries that would shortly include nearly every major collection across the continent — supplied the structural mechanism through which natural-philosophical work could now be communicated, preserved, and cumulatively built upon at a scale that no previous institutional form had permitted.

The institutional decision to publish in 1665 had specific consequences that would shape natural-philosophical practice across the following centuries. Robert Hooke's *Micrographia*, the great folio of microscopical observations published in January 1665 under the Society's imprimatur with engravings of the louse, the flea, the bee's stinger, the structure of cork (in which Hooke coined the term "cell" for the small chambers he observed), and dozens of other subjects, supplied the institutional demonstration that the Society could and would publish major natural-philosophical works of broad public interest. The volume reached a wide readership across England and the Continent within months of publication. Samuel Pepys, the diarist and naval administrator who would shortly become a Fellow and eventually serve as President, recorded sitting up until two in the morning reading *Micrographia* on January 21, 1665, describing it as "the most ingenious book that ever I read in my life." The institutional mechanism the Society had built was demonstrating, within five years of the founding, its capacity to bring natural-philosophical work to the broader educated public in forms that the public was responding to with extraordinary enthusiasm.

The Fellowship itself supplied the broader social network through which the Society's work connected to English political, ecclesiastical, and commercial life. The original twelve members of November 1660 were quickly supplemented by additional Fellows whose election was conducted by subscription and the assent of the existing membership. By the end of the first decade the Fellowship numbered approximately two hundred. The membership combined active natural philosophers — perhaps a quarter of the total — with a broader category of educated gentlemen, peers, bishops, physicians, merchants, military officers, and government officials whose interest in natural-philosophical work was active but whose personal contributions were principally financial, administrative, and social rather than directly experimental. The combination mattered. The active natural philosophers conducted the work. The broader membership supplied the financial subscriptions through which the Society's operations were funded, the political connections through which the Society's relationship with the court and the government was maintained, the social standing through which the natural-philosophical project was integrated into the broader cultural life of educated London, and the institutional ballast through which the Society could survive periods when its specific natural-philosophical activities were operating at lower intensity. The institutional form was Baconian in its design — Salomon's House had similarly combined active investigators with the broader administrative and political networks required for the work's continuation — but the form was now operating not in Bacon's imagined Bensalem but in actual Restoration London, with actual royal sanction, actual financial subscriptions, actual weekly meetings, and actual published proceedings reaching actual readers across actual European cities.

VII. The Comparative Configuration

The Royal Society was not the only natural-philosophical institution founded in the 1660s. The Académie des Sciences was established at Paris in 1666 by Jean-Baptiste Colbert, Louis XIV's principal minister, with the explicit purpose of providing the French state with natural-philosophical capacity comparable to what the Royal Society was building in England. The French institution differed structurally from the English one in ways that would shape its subsequent development and that illuminate, by contrast, what the English institutional configuration had specifically established.

The Académie was a state institution from its founding. Its members were salaried by the crown. Its research program was directed by royal officials, with Colbert himself supplying the strategic direction across the institution's first two decades. Its publications were conducted under royal authorization and were subject to censorship by the crown's officers. The membership was small — initially fifteen Pensionnaires, expanded over subsequent decades but always operating within firm numerical limits — and the membership was determined by royal appointment rather than by election from within the institution. The Académie produced, across the late seventeenth and eighteenth centuries, an enormous body of high-quality natural-philosophical work. Christiaan Huygens was an early member; Cassini, Roemer, Mariotte, Lavoisier (after his 1768 election), Laplace, and Lagrange all conducted significant portions of their careers within the institution. The French institutional configuration was operationally effective and produced, at the level of individual work, results comparable to and in many specific areas exceeding what the Royal Society's members were producing.

What the French configuration lacked, in comparison to the English, was the structural autonomy from political authority and the broader social integration with non-state institutional networks that the English configuration possessed. The Académie's dependence on royal patronage made it vulnerable to political disruption. The Revolution of 1789 suspended the institution and dispersed its members. Lavoisier was guillotined in May 1794 — the political authorities of the revolutionary period not finding his scientific eminence sufficient reason to spare him from the political settling of accounts. The Académie was reconstituted in 1795 as one of the four academies within the new Institut National, then renamed and reorganized successively across the political transformations of the following decades, eventually settling into its modern form within the Institut de France in 1816. The institutional continuity was preserved across the transformations, but the continuity was preserved through the larger French state's continuing commitment to maintaining a national scientific institution, not through the institution's own self-perpetuating governance. The French configuration was, structurally, a department of the French state operating under whatever political authority controlled the state at any given moment.

The Italian situation supplied a different comparative case. The Accademia del Cimento at Florence, founded under Medici patronage in 1657 and dissolved in 1667, had been operating as the

most productive natural-philosophical institution in Italy at exactly the moment the Royal Society was being founded in London. The Cimento conducted ten years of organized experimental work — on barometric pressure, the freezing of water, the behavior of fluids, the measurement of temperature — and produced its *Saggi di Naturali Esperienze* in 1667 as the published record of its experimental program. The Cimento's dissolution that same year, attributed variously to factional disputes among its members and to the loss of Medici patronage, eliminated the principal Italian natural-philosophical institution at exactly the moment the Royal Society was establishing itself. No comparable Italian institution emerged across the subsequent half-century. The Italian universities continued to operate but on the medical and humanistic patterns the Renaissance had established; they did not develop the kind of natural-philosophical institutional life that the Royal Society was building. By 1700 Italy had ceased to be the European center of natural-philosophical work that it had been at Galileo's death in 1642. The institutional vacuum had been filled, largely, by the English institution and by the French one.

The German states and the Low Countries had their own natural-philosophical activity across the same period but did not develop, in the seventeenth century, comparable institutional infrastructure. The German universities — Wittenberg, Leipzig, Heidelberg, the others — continued to operate as theological and philological institutions whose natural-philosophical capacities were modest and distributed across the individual professorial chairs rather than concentrated in dedicated experimental institutions. The Berlin Academy of Sciences was eventually founded in 1700 under the influence of Leibniz, but its operational development across the eighteenth century was slow and depended on the personal interests of successive Prussian monarchs. The Dutch universities — Leiden in particular — were producing significant natural-philosophical work in the seventeenth century, with Huygens, the Bernoullis (the family operating across multiple generations and various university appointments), Boerhaave (in medicine), and others. But the Dutch did not develop a national-level scientific institution comparable to the Royal Society. The work was being conducted at the universities and through individual patronage relationships, without the institutional concentration that the English configuration had achieved.

What the comparative configuration registers, by approximately 1670, is that the Royal Society was operating with structural features that no other European natural-philosophical institution had combined. The structural features were specific. The Society was a private corporate body operating under royal charter but governed by its own self-perpetuating Fellowship. It received no significant state funding — its operations were sustained by Fellows' subscriptions, by Hooke's salary supplied initially by Boyle's private patronage, by the income from publications, and by occasional gifts from private benefactors. Its research program was determined by the Fellows themselves rather than by any external authority. Its publications were issued under its own institutional authority. Its membership combined active natural philosophers with the broader networks of educated English society. Its operational continuity did not depend on the personal interest of any individual monarch or minister; the institution would survive subsequent monarchs (Charles II died in 1685; James II

was deposed in 1688; the institution continued through both transitions without interruption) and would adjust its political relationships as the broader political configuration shifted. The Society's structural autonomy from political authority was the defining feature that distinguished it from the Continental academies. The autonomy was operationally consequential. It meant that the institution's continuity would be determined by its own governance and its own membership rather than by the contingencies of political authority external to it.

The structural feature would shape, across the subsequent two centuries, what the institution would be able to accomplish. The institution would conduct its work, publish its findings, defend its members, integrate with the broader English educational and commercial networks, and survive the political and religious transitions that the seventeenth and eighteenth centuries would impose on the English state. The work the Society's first decade had established — the Baconian methodological commitment, the weekly meetings, the Journal Book records, the *Philosophical Transactions* publication, the Continental correspondence network, the combined Fellowship of active natural philosophers and broader educated supporters — would supply the operational framework within which the late seventeenth century's most consequential natural-philosophical work would shortly be conducted, communicated, and preserved.

The man whose work that framework would shortly be required to capture had been admitted to Trinity College, Cambridge, as a subsizar in June 1661, six months after the Royal Society's founding. He had taken his Bachelor's degree in 1665, returning to his family estate at Woolsthorpe in Lincolnshire later that year when the Cambridge plague closed the university. He had spent the eighteen months from August 1665 through April 1667 in what would later be called his *annus mirabilis* — the period in which he had developed the mathematical apparatus that would become the calculus, the optical investigations that would become his theory of color, and the gravitational hypothesis that would shortly produce the *Principia Mathematica* of 1687. Isaac Newton was unknown to the broader natural-philosophical community in 1670. He would shortly become known. The institutional apparatus the Royal Society had built across its first decade would supply the channel through which his work would reach the world.

The next part will examine how that institutional capture was conducted.

Part II — The Royal Society and the Capture of Newton's Generation

I. The Institutional Pattern at Operating Scale

By the late 1660s the Royal Society had established the operational patterns that would shape its work across the following century. The weekly meetings at Gresham College — disrupted by the Great Fire of 1666 and relocated to Arundel House through 1673, then returned to Gresham, and eventually moving to the Society's own premises at Crane Court in Fleet Street in 1710 — supplied the institutional locus at which natural-philosophical work was demonstrated and debated. The Curator of Experiments performed weekly demonstrations selected from the work members were conducting in their own laboratories. The Secretary maintained the correspondence network that connected the Society to the broader European natural-philosophical community. *Philosophical Transactions* appeared monthly under the Secretary's editorial supervision. The Fellowship, supplemented annually by new elections, accumulated a membership that combined the active natural philosophers conducting the work with the broader social network through which the work was supported, financed, and made culturally visible.

What the patterns produced, across the late 1660s and 1670s, was a quantity and quality of natural-philosophical work that exceeded what any other institution in Europe was generating. Robert Boyle's continuing experimental program supplied chemistry, pneumatics, and the foundations of experimental natural philosophy. *The Sceptical Chymist* of 1661 had argued against the Aristotelian four-element theory and the Paracelsian three-principle theory, replacing both with the corpuscular framework that would shortly become the operational basis of chemical investigation. *New Experiments Physico-Mechanicall, Touching the Spring of the Air* of 1660 had established what would become Boyle's Law — that the volume of a confined gas is inversely proportional to the pressure applied to it — through the air-pump experiments Hooke had conducted as Boyle's assistant. The continuing stream of Boyle's publications across the following two decades — *Considerations Touching the Usefulness of Experimental Naturall Philosophy* of 1663, *Experiments and Considerations Touching Colours* of 1664, *The Origin of Formes and Qualities* of 1666, the *Continuation* of his pneumatical experiments of 1669, and dozens of further volumes — placed before the European reading public an experimental program whose volume and rigor had no precedent.

Robert Hooke's work as Curator of Experiments paralleled Boyle's at the institutional level and exceeded Boyle's in the range of subjects it covered. Hooke was, by temperament and capacity, the

most versatile experimental natural philosopher the seventeenth century would produce. His *Micrographia* of 1665 supplied the microscopical foundation. His mechanical investigations produced what would shortly be called Hooke's Law of elasticity (announced in 1660, published in coded form in 1676 as *ut tensio sic vis*, "as the extension, so the force"). His optical work on color and light anticipated, in many specific respects, what Newton would shortly publish on the same subjects, with consequences for the priority disputes that would shape their relationship. His architectural and engineering work — Hooke served as Surveyor to the City of London after the 1666 Fire and as Christopher Wren's principal collaborator on the rebuilding — produced the Monument, several London churches, and the structural engineering knowledge that the rebuilding required. His paleontological work, conducted across the 1660s and 1670s and published posthumously in his *Posthumous Works* of 1705, anticipated by a century and a half what would later become geological and evolutionary science. The volume of Hooke's work, distributed across the disciplinary range of seventeenth-century natural philosophy, registered what an active experimental natural philosopher operating within the Royal Society's institutional framework could accomplish across a working career.

Christopher Wren's astronomical and mathematical work continued through his Savilian Professorship at Oxford and his Gresham Professorship in London. John Wallis at Oxford was conducting the mathematical investigations that produced his *Arithmetica Infinitorum* of 1656 and the broader development of the infinitesimal methods that would shortly be the foundation of the calculus. Edward Tyson conducted comparative anatomy. John Ray conducted botanical and zoological cataloguing whose published volumes (the *Historia Plantarum* of 1686–1704, the *Methodus Plantarum* of 1682, the *Synopsis Methodica Animalium* of 1693) supplied the foundations of subsequent systematic biology. John Flamsteed at the Royal Observatory at Greenwich, founded by Charles II in 1675 and operating under the Royal Society's general supervision, conducted the systematic astronomical observations that would shortly produce the *Historia Coelestis Britannica* and the foundation of modern observational astronomy.

The institutional mechanism through which this work was being conducted, communicated, and preserved was the Royal Society. The work was, in many specific cases, being done in laboratories and observatories the Society did not directly operate. Boyle's experiments were conducted at his London house. Hooke's were conducted at his Gresham College apartments and at the Royal Society's own quarters. Wren's were conducted at Oxford. Flamsteed's were conducted at Greenwich. But the Society supplied the institutional framework within which the work circulated — through the weekly meetings, through the Journal Book records, through *Philosophical Transactions*, through Oldenburg's correspondence network — and through which it was being made available to the subsequent generations who would build upon it.

This is the structural feature the case needs to register at the outset of Part II. The Royal Society was not, in its operational character, a research laboratory in the modern sense. It did not employ the

natural philosophers conducting the work; with the partial exception of Hooke's Curatorship and Oldenburg's Secretaryship, the Society did not pay salaries. It did not own most of the laboratories where the work was being conducted. It did not direct the research programs of its Fellows. What it did was supply the institutional framework that converted individual work into a continuing collective enterprise. The Fellows did the work. The Society captured it, recorded it, published it, defended it, and transmitted it to the broader community. The institutional memory accumulated through the operational mechanisms the Society maintained, week by week, year by year, decade by decade, regardless of which specific Fellows happened to be conducting the work at any given moment. The institution outlived its founding members. The work the institution captured would outlive the institution's first several presidencies. The trajectory was self-sustaining.

II. The Cambridge Outsider

Isaac Newton had been born at Woolsthorpe Manor in Lincolnshire on December 25, 1642 (Old Style; January 4, 1643 by the modern calendar), three months after the death of his father. His mother remarried when he was three. He was raised by his maternal grandmother through his childhood, attended the King's School at Grantham, and was admitted to Trinity College, Cambridge, as a subsizar — a poor scholar who paid his way by performing menial services for the wealthier students and the Fellows — in June 1661. He took his Bachelor's degree in 1665. He was elected to a Trinity Fellowship in 1667 and to the Lucasian Professorship of Mathematics in 1669, at the age of twenty-six, on the recommendation of Isaac Barrow, who had held the chair previously and who recognized in Newton a mathematical capacity that exceeded his own.

The intellectual trajectory that produced the work for which Newton would shortly be known had begun during the plague years of 1665 and 1666, when Cambridge was closed and Newton returned to Woolsthorpe for the eighteen months that he would later refer to as his *annus mirabilis* — the miracle year, though it was actually two years and the work distributed itself unevenly across them. During the period he conducted the mathematical investigations that produced what he called the method of fluxions, which Leibniz would shortly and independently develop as the differential calculus. He conducted the optical experiments — the famous prism experiments — that produced his theory of color, the demonstration that white light was composed of the spectrum of colored lights and that the colors could be separated and recombined through refraction. He developed the hypothesis of universal gravitation — the proposition that the same force that drew an apple to the earth's surface also held the moon in its orbit and the planets in theirs around the sun — through a calculation he conducted at Woolsthorpe that would shortly become the foundation of the *Principia*. The work was conducted in isolation. Newton's correspondence during the period was limited, his contact with the broader natural-philosophical community was modest, and the substance of what he had accomplished was unknown to anyone outside Cambridge until he began, in the early 1670s, to make selected portions of it visible to the Royal Society.

His relationship with the Society across the 1670s was strained from the beginning. Newton's first communication of significance was a letter of January 1672 describing the prism experiments and his theory of color, which the Society printed in *Philosophical Transactions* No. 80 in February 1672 under the title "A Letter of Mr. Isaac Newton, Professor of the Mathematicks in the University of Cambridge; Containing his New Theory about Light and Colors." The letter occupied seven pages of the journal and supplied the first European publication of the work that would shortly transform physical optics. It also produced the first of what would become a series of bitter conflicts between Newton and Robert Hooke.

Hooke had been conducting optical investigations across the previous decade, had published his own theory of light and color in *Micrographia*, and considered the Newton paper a derivative imposition on territory he had been working in. He produced, within a week of the paper's publication, a critical response that the Society referred to Newton for reply. Newton replied with characteristic acerbity, defending his work against Hooke's criticisms in terms that made the personal dimensions of the conflict visible. The exchange continued across several rounds. Other Continental natural philosophers — Christiaan Huygens, the Liège Jesuit Ignace Pardies, the French scholar Jean Lucas — entered the debate with their own criticisms. Newton's defensive responses became increasingly elaborate and increasingly hostile. By the autumn of 1672 he was writing to Oldenburg asking that his work no longer be published in *Philosophical Transactions* because the public exposure was producing precisely the kind of dispute he found intolerable. "I see I have made my self a slave to Philosophy," he wrote, "but if I get free of Mr Linus's business I will resolutely bid adew to it eternally, excepting what I do for my private satisfaction or leave to come out after me. For I see a man must either resolve to put out nothing new or to become a slave to defend it."

The episode registers what was at stake in the institutional capture of Newton's work. Newton was, by temperament, the most reclusive of the major seventeenth-century natural philosophers. He had no inclination to publish; his work satisfied him as an intellectual accomplishment without requiring public communication. He suspected the broader natural-philosophical community of intellectual mediocrity and personal hostility. He was extraordinarily sensitive to criticism and willing to absorb enormous costs to avoid it. Left to his own preferences, Newton would have continued his work at Cambridge across the 1670s and 1680s, would have continued to accumulate manuscripts of unpublished investigations, and would likely have died with the bulk of his work unknown to the broader community. The work would have survived, in some form, in the papers his heirs would have inherited; portions of it might have been recovered and published posthumously, the way much of his alchemical and theological work was actually handled across the eighteenth and twentieth centuries. But the *Principia* would not have existed as a published volume in the 1680s. The work would not have been available to the eighteenth-century continental mathematicians (Maupertuis, Clairaut, d'Alembert, Euler, Lagrange) who would shortly elaborate it into the dominant framework of European natural philosophy. The institutional capture that the Royal Society conducted across the 1680s was the operational mechanism through which Newton's

reclusiveness was overcome and his work was made available to the world.

The conduct of that capture is the subject of the central section of this Part. The figure who made it operational was Edmond Halley.

III. Halley and the Institutional Capture

Edmond Halley had been born in London in 1656, the son of a prosperous soap-boiler. He had been educated at St. Paul's School in London and at Queen's College, Oxford, where he matriculated in 1673 without taking a degree. He had begun, while still an undergraduate, the astronomical observations that would shortly establish his reputation: an account of sunspots published in *Philosophical Transactions* in 1676, observations of Jupiter and Saturn at conjunction, and the proposition that the southern hemisphere had not yet been adequately catalogued by European observers. He proposed to the Royal Society and to Charles II that he be permitted to conduct a southern-hemisphere observing program from St. Helena, the East India Company outpost in the South Atlantic. Permission was obtained; Halley sailed in November 1676; he spent eighteen months at St. Helena observing under difficult atmospheric conditions; he returned in May 1678 with a catalog of approximately three hundred and forty-one southern stars whose positions had not previously been adequately determined. The catalog was published in 1679 as *Catalogus Stellarum Australium*. Oxford granted him an M.A. by royal mandate. He was elected a Fellow of the Royal Society in November 1678, at the age of twenty-two. His career as a working astronomer with operational connections to the Society's institutional life had been established.

The decade that followed brought Halley into closer contact with the broader natural-philosophical community across both England and the Continent. He visited Hevelius at Danzig in 1679 to discuss the disputed claims that Hevelius's observational methods (using open sights rather than telescopic instruments) were producing observations comparable in accuracy to those of the telescopic observers. He visited Cassini at Paris in 1681. He observed and computed the orbit of the great comet of 1682 — the comet that would shortly bear his name when he predicted, in 1705, its return at approximately seventy-six-year intervals. He served as Clerk of the Royal Society from 1685, succeeding Francis Aston, and held the position through the period in which his most institutionally consequential work would be conducted.

The conversation that produced the *Principia* took place in January 1684 in a London coffee house. The participants were Halley, Robert Hooke, and Christopher Wren. They had been discussing the question of planetary motion, specifically the question of what mathematical relationship between the gravitational force and the distance from the sun would produce the elliptical orbits Kepler had established as the empirical pattern of planetary motion in his three laws of the early seventeenth century. Hooke claimed that an inverse-square relationship — gravitational force varying inversely with the square of the distance — would produce the elliptical orbits, and

that he could prove it. Wren, skeptical of Hooke's claim, offered a prize of a book worth forty shillings to whoever could supply a rigorous mathematical demonstration within two months. Hooke claimed he could but would withhold the proof to encourage others to attempt the work themselves. Halley considered the matter and concluded that he could not himself produce the demonstration. He decided to consult Newton at Cambridge.

The visit took place in August 1684. Halley posed the question. Newton replied, according to John Conduitt's later account from Newton himself, that he had calculated the answer some years earlier and that the inverse-square law did produce the elliptical orbit. Halley asked for the calculation. Newton could not find his papers from the earlier work. He promised to produce a fresh demonstration and send it to Halley. The promise was kept. In November 1684 Halley received from Newton a short manuscript titled *De motu corporum in gyrum* — "On the Motion of Bodies in Orbit" — containing the demonstration that the inverse-square gravitational law produced elliptical orbits with the focus at the central body, plus several related propositions about orbital motion under various force conditions. The manuscript was, in its substance, the foundational core of what would shortly become the *Principia*.

Halley recognized what he had received. He recognized, as he wrote to Newton, that the work had implications that exceeded the specific demonstrations the manuscript contained — that the same mathematical apparatus could be extended to the entire range of celestial mechanics, that the work could supply a comprehensive natural-philosophical account of the gravitational system Newton had glimpsed years earlier at Woolsthorpe. He pressed Newton to extend the work. Newton, with the institutional encouragement Halley supplied, began the systematic elaboration of the inverse-square law into what would shortly be the complete mechanical and gravitational theory.

The composition of the *Principia* across the following eighteen months was an extraordinary intellectual labor conducted at Cambridge in conditions of near isolation. Newton worked at the Lucasian Professorship, supplied with paper, ink, and the books from the Trinity library; he employed an amanuensis, also named Humphrey Newton (no relation), who copied his manuscript pages into the form that would be sent to the printer. Newton would later complain that Humphrey "understood not what he copied" — that the amanuensis was technically competent at the mechanical work of transcription but had no comprehension of the mathematical and physical content he was copying. The work proceeded across 1685 and into 1686 at a pace that suggested Newton was, despite his lifelong reluctance to publish, fully engaged with what he was producing. By the spring of 1686 Book I was complete in draft and was being sent to London for the Royal Society's consideration.

On April 28, 1686, Vincent presented Book I of what was now titled *Philosophiae Naturalis Principia Mathematica* to the Royal Society. Pepys was the Society's President. The Council met on May 19 and resolved that the Society should publish the work. Halley, in his capacity as Clerk, was directed to oversee the printing.

The institutional difficulty that emerged immediately concerned funding. The Society's publication budget for the year had been exhausted on the printing of Francis Willughby's *De Historia Piscium* — the History of Fishes — a folio volume with engravings that had absorbed several hundred pounds of the Society's resources. The Society had no funds available for the *Principia*. The Council resolved that the Society would print the work in a large quarto "at their own charge" but had no clear mechanism for paying the printer. Halley, who recognized the magnitude of what was about to be published and who had the personal financial resources to act on the recognition, agreed to underwrite the publication himself. He wrote to Newton on May 22, 1686, conveying the Society's decision and his own commitment: "I am intrusted to look after the printing of it, and will take care that it shall be performed as well as possible." Halley's personal underwriting of the publication was an act of institutional patronage at a level the Society's official mechanisms had been unable to provide. It is not unreasonable to say, as the historian I. B. Cohen and others have observed, that without Halley's personal commitment the *Principia* might have remained unpublished. The institution had decided to publish. The institution had not yet found the money. Halley supplied what the institution had not yet supplied.

The composition continued. Book I — on the general mathematics of orbital motion under central forces — was largely complete by mid-1686. Book II — on the motion of bodies in resisting media, including hydrodynamics and the motion of pendulums — was completed across late 1686 and early 1687. Book III — on the System of the World, applying the mathematical results to the actual motions of the planets, the moons of Jupiter and Saturn, the tides, the precession of the equinoxes, and the orbits of comets — was completed in early 1687. Newton briefly threatened to suppress Book III after a renewed conflict with Hooke, who had claimed priority on aspects of the gravitational hypothesis when he learned what Newton was preparing. Newton's letter to Halley of June 20, 1686, contains the famous passage: "Philosophy is such an impertinently litigious Lady that a man had as good be engaged in Law suits as have to with her. I found it so formerly & now I no sooner come near her again but she gives me warning." Halley managed the dispute through diplomatic correspondence, persuading Newton to retain Book III, persuading Hooke to accept what he could not change, and bringing the manuscript through to its completed form.

The *Principia* was published in July 1687. The print run was approximately three hundred to four hundred copies, a typical scale for a seventeenth-century scholarly folio. Halley wrote a Latin preface and a Latin ode celebrating Newton's achievement. The volume's title page bore the Royal Society's imprimatur as the publishing authority. The Society had no further financial exposure; Halley had absorbed the costs. Halley managed the distribution himself, sending presentation copies at Newton's direction and placing additional copies on consignment with London booksellers. The book reached its readership within months of publication. Christiaan Huygens received his copy in The Hague and immediately began studying it. Leibniz received his copy and produced his own elaboration of certain mathematical aspects in subsequent publications. The European natural-philosophical community recognized, within the first year of the *Principia*'s circulation, that

the work represented something the previous century of natural-philosophical investigation had been moving toward and had not yet achieved. The mathematical mechanics it supplied was, in its specific demonstrations and its general theoretical structure, the most comprehensive natural-philosophical work that European scholarship had yet produced.

What the institutional capture accomplished was the conversion of Newton's private investigations into a published work available to the broader European community. The conversion was conducted by an institutional apparatus — the Royal Society's decision to publish, Halley's personal underwriting and editorial management, the London printer's production, the European distribution network through which the published volumes reached their readers — that no individual could have replicated alone. Newton supplied the intellectual work. The Royal Society supplied the institutional mechanism. Without the institutional mechanism the work would not have been published in the form and at the time it was published. Without the published work, the eighteenth-century elaborations that would shortly produce what we now call Newtonian physics would not have occurred at the scale they actually occurred. The institutional capture of Newton's work was the load-bearing structure of the subsequent intellectual development. Newton was the genius. The Royal Society was the apparatus that made the genius operationally consequential at the European scale.

IV. The Newton Presidency and the Consolidation

Robert Hooke died in March 1703 at the age of sixty-seven. He had been the Royal Society's Curator of Experiments from its founding in 1662 through the late 1670s, had served as Secretary from 1677 to 1682, and had remained one of the Society's most active Fellows through his final decade. His death removed the principal obstacle to Newton's accession to the institutional position the natural-philosophical community had been increasingly expecting him to occupy.

Newton had spent the years since the *Principia*'s publication in a varied career that had taken him largely outside Cambridge. He had served two brief terms as Member of Parliament for the University of Cambridge — 1689 to 1690, and 1701 to 1702 — without distinguishing himself in either. He had suffered a serious nervous breakdown in 1693, the precise nature and causes of which remain disputed, during which he wrote accusatory letters to his friends Samuel Pepys and John Locke that he subsequently disavowed. He had moved to London in 1696 to take the Wardenship of the Royal Mint, an appointment arranged by Charles Montagu (Lord Halifax), the Whig political figure whose patronage had been one of Newton's main political connections through the 1690s. He had been promoted to Master of the Mint in 1699, a position he would hold until his death and that produced a comfortable personal income from the coinage operations. He had completed the Mint's recoinage program of 1696–1698 with administrative competence. He had pursued, in his capacity as Master, the systematic prosecution of counterfeiters, a number of whom were hanged on the testimony Newton's investigations had produced. He had transitioned, in his late fifties, from

Cambridge professor to London government official, with the operational consequences this implied for his subsequent intellectual work.

His election to the Royal Society Presidency on November 30, 1703, eight months after Hooke's death, registered the broader recognition that he had become, by his published work and his accumulated standing, the natural choice for the position. He would hold the Presidency for twenty-four years, from 1703 until his death in 1727 — by far the longest tenure of any President in the Society's history at that point, and a tenure that would shape the institution's character across the early eighteenth century and beyond.

What Newton did with the Presidency requires careful description. He was, by the institutional standards of the early eighteenth century, an active President in ways most of his predecessors had not been. He attended meetings regularly. He directed the Society's affairs at the Council level. He intervened in elections to determine the membership composition he wanted. He used his authority to advance his protégés and to suppress his enemies. He pursued long-standing personal feuds through institutional channels in ways that produced operational consequences for the men involved. The Flamsteed episode is the clearest case. Newton wanted Flamsteed's astronomical observations from Greenwich for use in revising the *Principia*'s lunar theory. Flamsteed, whose observational data had been collected at his own expense and whom he considered his personal property until he was ready to publish it, refused to release the work in incomplete form. Newton used his position as President of the Royal Society — and through the Society's Royal Observatory committee, his nominal supervision of Flamsteed's institutional position — to extract the observations and to arrange the publication, in 1712, of what was titled *Historia Coelestis* without Flamsteed's authorization. Flamsteed, on receiving the printed volumes, condemned the work as unfit for use and on his death in 1719 his widow recovered the unsold copies and burned them. Flamsteed's authorized *Historia Coelestis Britannica* would not appear until 1725, six years after his death and during the final two years of Newton's life.

The episode registered what the Newton Presidency could accomplish through the use of institutional authority. Newton was not a benign administrator. He was a vindictive and tenacious institutional operator whose use of the Royal Society's mechanisms produced clear winners and clear losers across his twenty-four years in office. The losers included Flamsteed, Hooke (whose reputation Newton's faction at the Society systematically diminished after his death, to the point that no portrait of Hooke survives — a remarkable lacuna in the visual record of an extraordinarily important figure in the seventeenth century scientific revolution), and the various Continental natural philosophers whose work Newton or his allies considered threatening to his own institutional position. The winners included Newton's Mint colleagues (some of whom received Royal Society Fellowships through his patronage), his mathematical disciples (Roger Cotes, William Whiston before his theological troubles, Henry Pemberton, and later Colin Maclaurin), and the broader Newtonian faction that would shortly dominate British mathematical and

natural-philosophical work across the first half of the eighteenth century.

What the Presidency also accomplished, however, was a major expansion of the Society's institutional reach and operational capacity. The Society moved from its Gresham College accommodations to its own premises at Crane Court in Fleet Street in 1710, purchased by the Society for £1,450. The membership grew from approximately one hundred and ten Fellows at Newton's accession in 1703 to approximately three hundred by 1739, a few years after his death. *Philosophical Transactions* continued to appear regularly, with its editorial work conducted by the Society's secretaries under increasingly systematic procedures. The Society's correspondence network expanded, with regular communication now maintained with the Paris Académie, the Berlin Academy (founded 1700), the Saint Petersburg Academy (founded 1724), and the various other European institutions that were emerging across the same period. The Society's library, archives, and instrument collection accumulated through donations and purchases. The institutional apparatus the founding generation had built was, by the end of Newton's Presidency, operating at a scale that exceeded what the founders had specifically envisioned.

The systematic Newtonization of British natural philosophy was the most operationally consequential outcome of the Presidency at the level of the broader intellectual life. Newton's mathematical mechanics, his theory of light and color, his approach to natural-philosophical investigation through experiment combined with mathematical demonstration — all of these became, across the first three decades of the eighteenth century, the operational orthodoxy of British natural-philosophical work. The transformation was not solely institutional. Newton's published work was producing the transformation on its own intellectual merits. But the institutional reinforcement that operated through the Royal Society's mechanisms, through the appointments Newton's allies obtained at Oxford and Cambridge, through the textbook publications and the popular expositions that successive generations of Newtonian authors produced, accelerated and consolidated the transformation in ways that pure intellectual merit would not have accomplished on its own timetable. By the 1720s the Newtonian framework was the operational language of British natural philosophy. By the 1730s it was the operational language of much of Continental Europe as well. The institutional capture of Newton's work had become the institutional capture of an entire generation's natural-philosophical work conducted in the framework Newton had supplied.

V. The Leibniz Dispute and What It Demonstrated

The most operationally visible institutional conflict of the Newton Presidency was the priority dispute with Gottfried Wilhelm Leibniz over the invention of the calculus. The dispute itself was complex on its own terms; the institutional dimensions are what concern this case.

The factual question was whether Newton or Leibniz had first developed the mathematical apparatus that would shortly become known as the calculus — the systematic method for analyzing

rates of change and accumulating quantities through the operations of differentiation and integration. Newton had developed his version of the method, which he called fluxions, during the *annus mirabilis* of 1665–1666 and had elaborated it across the following decade in unpublished manuscripts. He had communicated portions of the method in letters to Henry Oldenburg in 1676 and 1677, intended for transmission to Leibniz; the letters had been written in a partly coded form (Newton stating certain key results in anagrams) intended to preserve his priority while making the work available for European discussion. Leibniz had developed his version of the method, with different notation and a somewhat different conceptual framework, across the late 1670s; he had published it in 1684 in the *Acta Eruditorum* of Leipzig. The published Leibnizian calculus, with its differential and integral notation that proved more practically usable than Newton's fluxional notation, had rapidly become the European operational version of the method across the 1690s and 1700s. By 1700 most working European mathematicians who used the calculus were using Leibniz's version. The Bernoullis at Basel had developed it extensively. L'Hôpital had published the first textbook of the differential calculus in 1696, drawing on Leibniz's published work.

The priority dispute emerged, at the institutional level, in the first decade of the eighteenth century. Newton's circle in London, including Halley, Roger Cotes, William Jones, and the broader Newtonian faction at the Royal Society, considered that Newton's earlier private development of fluxions established his priority on the invention; that Leibniz had derived his own version from Newton's communications to Oldenburg in 1676 and 1677; and that the Continental adoption of Leibnizian rather than Newtonian notation represented a kind of intellectual theft that the Royal Society should formally repudiate. Leibniz's circle on the Continent, including Johann Bernoulli at Basel and the broader European mathematical community, considered that Leibniz had developed his version independently of Newton's earlier work; that the published Leibnizian calculus was, in its content and structure, an independent development whatever its temporal relationship to Newton's unpublished work; and that the Newton faction's claims of priority through unpublished manuscripts were an unfair retrospective claim against a clearly priority-establishing publication by Leibniz.

The institutional resolution Newton pursued through the Royal Society was operationally instructive. In 1711 the Royal Society appointed a committee to examine the priority dispute. The committee was composed entirely of Newton's allies; Leibniz was not consulted and was given no opportunity to present his case. The committee produced, in 1712, a report titled *Commercium Epistolicum de Analysi Promota* — a published documentary collection of the relevant correspondence and manuscripts, with extensive commentary establishing Newton's priority. The report was, by the historiographical work of the eighteenth and subsequent centuries, written largely by Newton himself under the formal authorship of the committee. The institutional finding was that Newton had been the first inventor and that Leibniz's calculus had been derived from Newton's earlier work. The finding was published under the Royal Society's official imprimatur. Newton wrote, in 1715, an anonymous review of the *Commercium Epistolicum* for *Philosophical*

Transactions that elaborated the case against Leibniz; the anonymous review was, also unsurprisingly, his own work.

The institutional finding did not settle the question on the Continent. European mathematicians continued to use Leibnizian notation, continued to develop the calculus through the Leibnizian framework, and continued to consider that Leibniz's published work established a genuine priority independent of whatever Newton had developed earlier in unpublished manuscripts. The historiographical judgment that emerged across the subsequent two centuries was that Newton and Leibniz had developed the calculus independently of each other — that whatever Newton had communicated to Leibniz through the 1676 and 1677 letters had been too limited and too coded to constitute the basis for Leibniz's subsequent independent elaboration of the method, and that Leibniz had supplied the published form of the calculus that the European mathematical community had been able to adopt and elaborate. Both men had genuinely invented what they invented; neither had stolen from the other. The Royal Society's 1712 finding was institutionally definitive within the Newton faction's sphere of influence but did not reflect what had actually happened.

What the episode demonstrates, for the purposes of this case, is that the institutional capture of natural-philosophical work can be deployed for purposes that exceed the institution's stated commitment to disinterested investigation. The Royal Society's motto was *Nullius in verba* — take nobody's word for it. The *Commercium Epistolicum* was an exercise in taking Newton's word for it, conducted under the Society's institutional authority and published under the Society's imprimatur. The institutional mechanism that had been built to verify natural-philosophical claims through experimental investigation was being used, in this case, to deliver an institutional verdict on a priority dispute through procedures that violated the Society's own foundational commitments. The institution could be used for things its founders had not specifically endorsed. The institutional memory that the case has been tracking included, as a feature of its operational reality, the capacity to be deployed for the personal and factional purposes of whoever held institutional authority at any given moment. The trajectory was not entirely benign.

The point should be registered without softening it because the rest of this case will continue to track institutional development across centuries and the institutional capture of natural-philosophical work will continue to produce, alongside its productive consequences, the specific factional and personal consequences that the Leibniz dispute supplied at high resolution. The institutional memory is the load-bearing structure of cumulative scientific work. It is also the structure through which whatever the institution's current leadership wants to advance, advances; and through which whatever the institution's current leadership wants to suppress, gets suppressed. The trajectory the case is tracking has its specific features. The features are operationally real and have their specific costs alongside their specific benefits.

VI. The Buried King

Newton died on March 20, 1727, at his house in Kensington, in his eighty-fifth year. He had retained the Mastership of the Mint and the Presidency of the Royal Society to his death. He had been knighted by Queen Anne in 1705 — only the second natural philosopher to be knighted in English history, after Francis Bacon — though the knighthood was conferred for political rather than scientific reasons during a royal visit to Cambridge in the run-up to the parliamentary election of that year. He had been a Fellow of the Royal Society for fifty-five years, since his election in January 1672. The *Principia* had appeared in three editions during his lifetime: the first of 1687, the second of 1713 (revised and expanded with Cotes's editorial collaboration), and the third of 1726 (further revised with Pemberton's collaboration). His *Opticks* had appeared in 1704 and had been through three editions of its own. His career had been the most institutionally celebrated of any natural philosopher in European history to that point.

His funeral registered what the institutional configuration he had operated within had accomplished at the cultural level. The body lay in state in the Jerusalem Chamber at Westminster Abbey for the eight days between his death and the burial. The funeral procession on March 28, 1727, was led by the Lord Chancellor and included two dukes — Montrose and Roxburgh — and three earls — Pembroke, Sussex, and Macclesfield — as the pallbearers. The chief mourner was Sir Michael Newton, a distant relative. Most of the Fellows of the Royal Society followed the coffin. The procession moved through the Abbey to the grave site at the entrance to the choir, where the Latin inscription on the slab reads, in its English translation: "Here lies that which was mortal of Isaac Newton." Newton was the first scientist to be buried at Westminster Abbey. The precedent he established would, across the following two centuries, produce the burial of Charles Darwin in 1882, Ernest Rutherford in 1937, J. J. Thomson in 1940, and the broader pattern by which English science would be commemorated through interment in the national church.

Voltaire was visiting England at the time of Newton's funeral. He attended the procession. His subsequent account, published in the *Lettres philosophiques* of 1734 (the *Lettres anglaises* of 1733 in the English edition), recorded the observation that became the period's most quoted single line about what the funeral demonstrated. "He was buried like a king who had done well by his subjects." The observation registered the operational point. Newton had not been a king. He had been a natural philosopher. The state had buried him with the ceremonies appropriate to a national figure of the highest rank. The state had registered, by the institutional act of conducting a state funeral for a natural philosopher and interring him among the kings, prime ministers, generals, and ecclesiastical figures whose graves the Abbey had collected across the centuries, that natural philosophy had become an activity worthy of equivalent national honor. The institutional capture of natural-philosophical work was now being publicly commemorated by the state through ceremonies that placed natural-philosophical achievement at the same cultural register as political, military, and religious achievement.

The monument that William Kent designed and Michael Rysbrack sculpted for the grave site was installed in 1731. The Latin inscription on the monument supplied the public commemoration: "Here is buried Isaac Newton, Knight, who by a strength of mind almost divine, and by mathematical principles peculiarly his own, explored the course and figures of the planets, the paths of comets, the tides of the seas, the dissimilarities in rays of light, and what other scholars had previously imagined the inexplicable properties of colors. He was diligent, sagacious, and faithful in his expositions of nature, antiquity, and the holy Scriptures. He vindicated, in his philosophy, the majesty of God almighty, and exhibited, in his manner of life, the simplicity of the Gospel. Mortals rejoice that there has existed such and so great an ornament of the human race." The inscription registered what the institutional configuration had produced as the public account of what natural philosophy was. Natural philosophy was an activity that vindicated the majesty of God, ornamented the human race, supplied a manner of life worth public commemoration, and produced intellectual achievements of a kind the state should honor through the most prestigious available institutional means.

Alexander Pope's couplet, written for the monument but not actually placed on it, supplied the popular version: "Nature, and Nature's Laws lay hid in Night: / God said, *Let Newton be!* and All was Light." The couplet would be remembered. The popular cultural account of Newton's achievement — the man who had been called forth by divine sanction to illuminate the natural world that had previously been hidden — would shape the broader cultural reception of natural-philosophical work across the subsequent century. Natural philosophy was being installed in the broader cultural imagination as an activity whose practitioners stood at the apex of human intellectual achievement, whose work was a form of divine revelation, and whose contributions deserved the kind of national commemoration the state had been accustomed to conferring on military and political leaders.

The institutional accomplishment had taken approximately a century. Bacon had supplied the institutional vision in *The New Atlantis* of 1627. The Hartlib circle and the Wadham group had supplied the operational precursors across the 1640s and 1650s. The Royal Society had been founded in 1660 and had received its charter in 1662. The Society had captured Boyle's work, Hooke's work, and the broader work of the first generation of English natural philosophers across the 1660s and 1670s. The Society had captured Newton's work through Halley's institutional labor across the 1680s. The Newton Presidency had consolidated the institutional configuration across the early decades of the eighteenth century. The state funeral and Westminster burial of 1727 had registered, at the level of public ceremony, what the institutional configuration had produced as the cultural prestige of natural-philosophical work.

The configuration was now operational. The institutional memory the case has been tracking was now being maintained by an apparatus whose mechanisms — the weekly meetings, the Journal Book records, the *Philosophical Transactions*, the European correspondence network, the

Fellowship's combined active-researcher and broader-supporter membership, the institutional defense of priority claims, the institutional commemoration of major contributors — would continue to operate across the following century and beyond. What the case will track across the next four Parts is what the institutional memory produced as it was extended through subsequent generations and integrated with the broader institutional configurations that would emerge across the eighteenth and nineteenth centuries — the dissenting academies, the provincial societies, the Royal Institution, the British Association for the Advancement of Science, the mechanics' institutes, the specialist societies, and the broader institutional ecology of British science that would shortly produce the world's first industrial economy and the world's first sustained tradition of cumulative scientific work at industrial scale.

The trajectory was already in motion. The institutional configuration had been built. The cultural prestige had been established. The next generations would inherit what the founders had constructed and would extend it in directions the founders had not specifically planned.

The next Part will examine the parallel educational infrastructure that the Anglican exclusion of the dissenters had, by historical accident, produced alongside the Royal Society's central apparatus, and that would shortly supply much of the technical leadership of the coming industrial economy.

Part III — The Dissenting Academies and the Parallel Educational System

I. The Exclusion of 1662

The Royal Society had been chartered in July 1662. Three months later, on August 24, 1662, a separate piece of Restoration legislation produced an institutional development whose consequences would shape the case this work has been tracking across the following century and a half. The Act of Uniformity required every minister, college fellow, and schoolmaster in England to subscribe formally to the revised Book of Common Prayer, to accept the doctrine of episcopal ordination, to renounce the Solemn League and Covenant of 1643 that had bound the Puritan ministers to the Presbyterian discipline, and to declare unequivocally that no obligation lay on him from any previous oath that conflicted with his conformity to the Church of England as now reconstituted. The deadline for subscription was set for St. Bartholomew's Day. Ministers who refused to subscribe were ejected from their livings.

Approximately two thousand ministers refused. The exact figure has been disputed by historians — Edmund Calamy's revised count of 1934 identified slightly more than that, while modern revisionist studies have produced somewhat lower figures depending on how the ejections of 1660 and 1661 are counted alongside those of 1662 itself. The aggregate is clear enough. Something close to one-fifth of the English clergy left the established church in 1662 rather than accept the doctrinal and ceremonial conditions the Act of Uniformity imposed. The episode became known among the dissenting communities that emerged from the ejection as the Great Ejection, or as Black Bartholomew's Day in conscious echo of the St. Bartholomew's Day Massacre of French Protestants in 1572 that had occurred ninety years earlier on the same calendar date.

The Act of Uniformity was the first piece of what became known as the Clarendon Code — the broader set of Restoration religious legislation that included the Corporation Act of 1661 (restricting municipal office to those who had received the Anglican sacraments), the Conventicle Act of 1664 (prohibiting religious meetings of more than four persons outside the established church), the Five Mile Act of 1665 (forbidding ejected ministers from residing within five miles of any city or town in which they had previously served), and the Test Act of 1673 (requiring office-holders to receive Anglican communion and to disavow the Catholic doctrine of transubstantiation). The Code's combined effect was to create, in the English religious-political settlement of the 1660s and 1670s, a substantial population of educated Protestants who could not in conscience subscribe to the Anglican settlement and who consequently could not hold any office, attend any university, or

conduct any religious activity that the established church's authority controlled. The population was concentrated in the urban commercial classes of London and the major provincial cities, in particular regional pockets where Puritan congregations had been strong before 1660 (Lancashire, the West Riding, the eastern counties), and among educated families whose theological convictions placed them outside the Anglican structure the Restoration had reimposed.

What the Code had not specifically considered, in its drafting, was what the educational requirements of this excluded population would shortly produce. Dissenting families could not send their sons to Oxford or Cambridge; matriculation at both universities required Anglican subscription, a requirement that would remain in force at Oxford until 1854 and at Cambridge until 1856. Dissenting clergy could not be trained at Oxford or Cambridge for the same reason. The dissenting communities required, if they were to continue to exist as functioning religious bodies whose ministry could be reproduced across generations, an alternative educational infrastructure through which their young men could be prepared for the ministry and through which their broader educated laity could be formed in the intellectual disciplines that an educated English Protestant was expected to possess. The infrastructure did not exist in 1662. It would have to be built.

The construction proceeded across the next half-century through the most informal of possible arrangements. Ejected ministers, finding themselves without parish positions but in possession of substantial theological and classical learning, opened private schools and small academies that received the sons of dissenting families and conducted what amounted to university-level education in the form of household instruction. Richard Frankland opened an academy at Rathmell in Yorkshire in 1670. Thomas Doolittle conducted one at Islington from approximately 1672. Charles Morton operated an academy at Newington Green, north of London, from approximately 1675; among his students was Daniel Defoe, who would later supply, in his various polemical writings, defenses of the dissenting educational tradition that had formed him. Theophilus Gale conducted an academy at Newington from 1666. Henry Hickman operated one at Stourbridge. The pattern was distributed. Approximately twenty-three dissenting academies have been documented as operating across the period from 1662 through the end of the seventeenth century, with the operations conducted in private houses, often illegally under the terms of the Conventicle Act and the Five Mile Act, with the tutors moving their operations periodically to evade the authorities' prosecution.

The Toleration Act of 1689, passed by the Convention Parliament under William and Mary in the wake of the Glorious Revolution, supplied a measure of legal protection. Dissenters were now permitted to conduct religious worship in licensed meeting houses, to preach without ecclesiastical authorization provided they accepted the Trinitarian doctrines of the Thirty-Nine Articles, and to operate schools for the education of their own children. The Toleration did not lift the Test and Corporation Acts; dissenters remained excluded from offices of state, from municipal corporations, and from the universities. But the operational situation of the academies was now more secure. The tutors no longer needed to relocate their operations to evade prosecution. The academies could

occupy permanent premises, could announce their courses publicly, and could accept students whose families wished to send them without fear of legal sanction. The dissenting educational infrastructure entered, after 1689, a period of institutional consolidation that would supply the operational framework of its subsequent development across the eighteenth century.

What the institutional infrastructure had not yet developed, in the period before 1700, was the curricular distinctiveness that would shortly become its defining feature. The early academies taught substantially the same curriculum as Oxford and Cambridge — the classical languages, scholastic logic, theology, mathematics in its older form — adapted to the smaller scale of household instruction and to the specific theological commitments of the dissenting communities. The distinctive curriculum of the eighteenth-century academies would emerge across the early decades of the following century, through the work of specific tutors whose pedagogical decisions began to differentiate the dissenting educational tradition from the curriculum the established universities were maintaining.

The figure through whose work the differentiation became consequential at the institutional level was John Jennings.

II. The Jennings Lineage

John Jennings opened his dissenting academy at Kibworth in Leicestershire in 1715. He had been educated at the academy of Thomas Rowe at Newington Green, north of London — the same institutional lineage from which Defoe had emerged — and had served as Independent minister at Kibworth for several years before opening the academy as an addition to his pastoral work. The institution he operated was small: typically a dozen students at any given time, lodged in his own house or in nearby village accommodations, conducted on a four-year curriculum that combined the standard classical and theological subjects with a series of innovations that the academy's subsequent reputation would be built on.

The innovations were specific. Jennings taught his courses in English rather than Latin, the standard medium of university instruction at Oxford and Cambridge throughout the eighteenth century. He used a broader range of textbooks than the English universities employed, drawing on Continental Reformed and Lutheran sources alongside the standard English authors. He encouraged his students to read both sides of theological and philosophical disputes — to read Locke alongside Cudworth, the Arminians alongside the Calvinists, the deists alongside the orthodox responses — and to form their own judgments rather than receive a fixed body of doctrine. He included in his curriculum the new natural philosophy of the Royal Society circle: Newton's *Principia* and *Opticks*, Boyle's experimental works, Locke's *Essay Concerning Human Understanding*, the broader literature that the universities of the period were teaching only in attenuated and conservative versions. He taught modern history alongside ancient history, and he taught the political theory of

Locke and his Whig successors as serious intellectual material rather than as occasional reading. His students were, by the time they completed his four-year course, formed in a substantially broader and more current intellectual configuration than the contemporaneous Oxford or Cambridge graduate would have absorbed.

Jennings died in 1723, at the age of approximately thirty-five, before his academy had operated for a full decade. The Kibworth academy closed at his death. What survived him was the curriculum he had developed and the specific group of students who had completed his course, several of whom would shortly carry forward his pedagogical pattern in their own institutional work.

Philip Doddridge was one of those students. Born in London in 1702, the youngest of twenty children of a merchant family, orphaned at thirteen, supported in his education by a friend of his father's named Samuel Clark, Doddridge had enrolled at Jennings's academy in 1719 at the age of seventeen. He had completed the four-year course by 1723, the year of Jennings's death. He had served briefly as minister at Kibworth himself, taking over the pastoral charge his tutor had held, and had moved to Market Harborough by the late 1720s. The Coward Trust — a charitable fund established by the merchant William Coward to support the dissenting interest, administered after Coward's death in 1738 by trustees including Isaac Watts and others — had been looking for a suitable figure to revive the academy tradition that Jennings's death had interrupted. On April 10, 1729, a meeting of dissenting ministers at Lutterworth discussed the matter. The discussion settled on Doddridge as the appropriate figure to lead a new academy. Doddridge agreed.

The new academy opened in July 1729 at Market Harborough with three divinity students and several others. In December of the same year Doddridge moved both his pastoral work and the academy to Castle Hill Chapel in Northampton, where he had accepted the pastorate. The Northampton Academy, as it would shortly be known, would operate from late 1729 through Doddridge's death in 1751 — twenty-two years of continuous operation under Doddridge's direct supervision, with the curriculum he had developed from Jennings's example and that he would shortly elaborate into the most influential dissenting educational model of the eighteenth century.

Doddridge's curriculum at Northampton followed Jennings's pattern and extended it. The course ran four years. The instruction was in English. The reading lists included the full range of contemporary European and English philosophical, theological, and scientific writing, with students expected to engage seriously with positions Doddridge himself did not endorse. Doddridge's lectures on philosophy, ethics, and theology were taken down in shorthand by his students; the lectures circulated in manuscript form across the dissenting educational community and were published after his death as *A Course of Lectures on the Principal Subjects in Pneumatology, Ethics, and Divinity* (1763), supplying the curriculum to subsequent academies for two decades after his death. The curriculum included substantial work in mathematics and natural philosophy. Doddridge corresponded with the Royal Society Fellows of the period and incorporated their published work into his lectures. The students who graduated from Northampton across Doddridge's

twenty-two-year tenure — approximately one hundred forty in total — went into the dissenting ministry, into medicine, into the professional and commercial occupations the dissenting communities were developing, and increasingly into the natural-philosophical and educational work that the dissenting tradition would shortly produce in disproportionate numbers.

What Northampton produced, by the time of Doddridge's death in 1751, was a curricular and institutional template that the broader dissenting educational community had absorbed. Northampton's academic standards had become high enough that several Anglican families had begun sending their sons there, despite the formal religious differences, because the education offered was operationally better than what was available at Oxford or Cambridge for sons not intended for the Anglican clergy. The dissenting academies had reached the operational position where their educational quality was beginning to attract students from the established religious community whose universities had previously been the exclusive option. The exclusion that had produced the academies was, by the middle of the eighteenth century, beginning to produce institutional consequences that exceeded the religious-political dispute that had created it.

Doddridge died in October 1751. The Northampton Academy did not survive his death; his successor Caleb Ashworth moved the operation to Daventry, where it would continue under Ashworth's leadership from 1752 until his death in 1775, with Thomas Belsham succeeding him through 1789. The Daventry Academy operated essentially as the institutional continuation of Doddridge's Northampton Academy, conducting the same curriculum from the same set of Doddridge's published lectures, training the same kind of students for the same range of subsequent occupations. The institutional lineage — Jennings at Kibworth from 1715, Doddridge at Northampton from 1729, Ashworth and Belsham at Daventry from 1752 — would carry the dissenting educational tradition across the entire central period of the eighteenth century, through nearly seventy-five years of continuous institutional development conducted within a single pedagogical lineage that began with one man's small academy in a Leicestershire village.

III. Warrington and the Athens of the North

The most operationally consequential of the eighteenth-century dissenting academies was founded at Warrington in Lancashire in 1757. The town was, in itself, an unlikely location for a major educational institution. Warrington was a small market town on the Mersey River between Liverpool and Manchester, with a population of approximately five thousand in the middle of the century, no university tradition, no aristocratic patronage of any particular note, and no specific intellectual standing in the broader English landscape. What it had was a substantial dissenting community whose principal congregation worshipped at the Cairo Street Chapel under the ministry of John Seddon, a graduate of Doddridge's Northampton Academy, and a group of dissenting laymen and ministers in the surrounding Lancashire and Cheshire region who had concluded that the existing academies — Daventry under Ashworth, a few smaller institutions at Kendal and Findern — were inadequate to the educational needs of the broader region's dissenting community.

The planning had begun in 1753 under Seddon's leadership. The funding had been raised across the following four years through subscriptions from the regional dissenting community. The academy was formally constituted in June 1757 and opened with three initial tutors: John Taylor, an Arian theologian from Norwich, as tutor in divinity; John Holt as tutor in natural philosophy (the contemporary term for what would shortly include physics, chemistry, astronomy, and the broader range of experimental sciences); and John Aikin as tutor in classics. The initial site was the Cairo Street Chapel itself; the academy would shortly acquire a large red brick house in the town as its permanent quarters. The student body began at a modest scale — perhaps two dozen students in the first years — and grew to approximately thirty to forty at the institution's peak in the 1760s.

Warrington's curriculum extended what Doddridge's Northampton had established. The English-language instruction continued. The reading lists were updated to incorporate the further intellectual developments of the half-century since Jennings had opened Kibworth — Hume's *Essays Moral and Political* of 1741 to 1742 and his *History of England* of 1754 to 1761; Adam Smith's *Theory of Moral Sentiments* of 1759 and shortly thereafter the *Wealth of Nations* of 1776; the broader Scottish Enlightenment material that was being produced at Edinburgh and Glasgow in the 1750s and 1760s; the Continental philosophical material of the Encyclopedist circle and the German Aufklärung. The natural philosophy curriculum was expanded substantially. Holt taught what would now be called experimental physics — mechanics, hydrostatics, optics, and the broader range of subjects that the Royal Society's published work had made available. The academy acquired laboratory equipment for chemical and electrical demonstrations. The students conducted experiments rather than only reading about them.

The pedagogical innovation that mattered most for the broader trajectory was the curricular emphasis on the practical subjects that the rising commercial and industrial economy required. The academy taught chemistry, electricity, logic, magnetism, mathematics, optics, pneumatics,

alongside the more traditional ethics, philosophy, and theology. The curriculum was not, in its design, exclusively theological. Of the approximately four hundred students who passed through Warrington across its twenty-nine years of operation, only about sixteen percent were preparing for the dissenting ministry. The remainder were preparing for medicine, for law (insofar as dissenters could practice law in a polity where they were excluded from the bar), for commercial careers, for the growing technical occupations the period was producing, and for the broader range of educated middle-class life that the eighteenth-century English economy required. The academy understood itself, by its own institutional self-conception, as supplying education for what its prospectus called "civil and active life" — not exclusively for ministry, but for the broader range of occupations an educated dissenting gentleman might occupy.

Joseph Priestley arrived at Warrington as tutor in modern languages and rhetoric in 1761, at the age of twenty-eight. He had himself been educated at the Daventry Academy under Ashworth in the late 1740s and early 1750s — the institutional continuation of Doddridge's Northampton — and had served briefly as Independent minister at Needham Market in Suffolk and at Nantwich in Cheshire before the Warrington appointment. His Nantwich school had given him his first experience of teaching natural philosophy to students; the Warrington appointment was officially in modern languages, but his interests and his subsequent work would push the institution further into the experimental sciences than its original constitution had anticipated.

Priestley's tenure at Warrington, from 1761 to 1767, was the period in which the academy reached the operational peak that would secure its broader reputation. He published his *Rudiments of English Grammar* in 1761 (the year of his arrival), which was widely adopted as a school textbook and influenced the development of English grammatical scholarship for the following half-century. He published his *Chart of Biography* in 1765 and *A New Chart of History* in 1769, supplying graphical timelines that became, in their period, the dominant visual representations of historical knowledge and went through fifteen editions of the *New Chart* by 1816. He conducted his electrical experiments at Warrington from 1765 to 1767, producing the *History and Present State of Electricity* of 1767 that supplied the foundational survey of the field. He delivered his lectures on history that were published in 1788 as *Lectures on History and General Policy*, lectures that were subsequently adopted as the standard course at the New College at Hackney, at the Manchester Academy, and at Brown, Princeton, Yale, and Cambridge in the United States. The trustees of Warrington Academy were sufficiently impressed with his work that they arranged for the University of Edinburgh to grant him a Doctor of Laws degree in 1764 — Edinburgh being one of the few British universities whose statutes permitted the granting of degrees to dissenters.

Priestley's friends and colleagues at Warrington during his six years there included John Aikin (the academy's classics tutor), Aikin's sister Anna Letitia Aikin (later Barbauld, the educational writer and poet), and the various visiting figures who passed through the institution. Josiah Wedgwood, the potter and industrial entrepreneur who would shortly become one of the central

figures of the Lunar Society at Birmingham, met Priestley at Warrington in 1762 after a fall from his horse brought him to the town for medical treatment. The two men corresponded across the following decades on the chemistry of glazes, ceramics, and the broader chemical processes that Wedgwood's industrial work required, exchanging laboratory equipment and chemical samples through the channels their friendship had established. Wedgwood would later create a Jasperware medallion of Priestley in cream-on-blue. The relationship registered something operationally consequential about what Warrington was producing. The academy was not simply training future ministers and physicians. It was forming a network of dissenting natural philosophers, industrial entrepreneurs, and educated middle-class men whose subsequent collaborations would shortly produce the technical foundations of the industrial economy.

The contemporary epithet by which Warrington came to be known across the late eighteenth century was "the Athens of the North." The phrase registered what observers in the period saw the academy as accomplishing. Warrington was, in its operational years, a small Lancashire town whose dissenting academy had attracted a faculty whose intellectual standing rivaled the major European universities and whose graduates were entering occupations across the rising industrial economy at a rate the formal universities could not match. The phrase was hyperbolic in its specifics; Warrington was not Athens. But the recognition the phrase registered was operationally accurate. The dissenting academies, by the 1760s and 1770s, had achieved a kind of cultural standing within the broader English educational landscape that exceeded their formal institutional position and reflected what they were actually producing.

The academy did not survive its financial difficulties. Falling enrollment, internal disciplinary problems among the students of the 1770s, theological disputes within the academy's tutoring body, and the broader financial pressures of operating an institution dependent on subscription support without endowment all contributed to the academy's decline across the 1770s and early 1780s. The institution closed in 1782. Its formal dissolution was completed in 1786, with the library, equipment, and remaining financial assets transferred to the new Manchester Academy that opened in the same year. The Manchester Academy would continue the dissenting educational tradition into the nineteenth century, relocating to York in 1803 and back to Manchester in 1840 and eventually merging with Oxford in 1888 as Manchester College, which would become Harris Manchester College, Oxford. The institutional lineage — Jennings at Kibworth (1715), Doddridge at Northampton (1729), Ashworth and Belsham at Daventry (1752), the Warrington Academy (1757–1786), the Manchester Academy (1786 onward), the New College at Hackney (1786–1796) — would carry the dissenting educational tradition through to the eventual repeal of the Test Acts in 1828 and the opening of London University in 1826, when the formal exclusion that had produced the academies was finally lifted and the institutional logic shifted.

IV. The Curricular Innovation in Operational Detail

What the dissenting academies had accomplished, by the period of Warrington's operation in the 1760s and 1770s, was a curricular innovation whose specific features the rest of this case will continue to register because the features would shortly supply the technical foundations of the industrial economy. The features deserve to be specified at the level of operational detail.

The first feature was instruction in English. Oxford and Cambridge conducted their teaching in Latin throughout the eighteenth century, with the lectures, the disputations, and the examinations conducted in the classical language. The justification was traditional — the classical languages were the medium of European scholarship and the proper foundation of an educated gentleman's intellectual life — and the practical consequence was that the universities' instruction operated in a medium whose mastery itself required years of preparatory work and whose use limited the range of contemporary intellectual material that could be incorporated into the curriculum. The dissenting academies abandoned this. Instruction was in English from the founding of the academies onward, and the abandonment of Latin instruction permitted the incorporation of contemporary English-language intellectual material — Newton's *Principia* read in the original Latin alongside English commentaries and elaborations, Locke read in his English originals, Adam Smith and David Hume and Joseph Butler read in the prose they had written in, the periodical literature and pamphlet polemics of the contemporary intellectual culture incorporated as live texts rather than handled as raw material requiring translation. The students who graduated from the academies were prepared to participate in contemporary intellectual life directly, in the medium that intellectual life was being conducted in, rather than through the mediation of the classical languages that the universities required.

The second feature was the curricular emphasis on modern subjects alongside the classical and theological foundations. The academies taught modern languages — French, German, Italian — as serious academic subjects. They taught modern history alongside ancient history, with the recent European past treated as material for systematic study rather than as occasional reading. They taught political economy as it was being developed by the Scottish Enlightenment figures, with Smith's *Wealth of Nations* incorporated into the Warrington curriculum within a few years of its publication in 1776. They taught experimental natural philosophy through demonstrations, laboratory work, and the systematic study of the Royal Society's published proceedings. They taught practical mathematics alongside the classical mathematics that the universities had been teaching — arithmetic and algebra and the methods of practical computation that commercial and engineering work required, rather than only the Euclidean geometry and the higher mathematics that the universities had inherited from the medieval curriculum.

The third feature was the pedagogical practice of presenting competing positions and requiring students to engage with the arguments on both sides rather than absorb a fixed body of doctrine.

Doddridge's lectures at Northampton had institutionalized this practice. His curriculum required students to read Locke alongside the Cambridge Platonists who had opposed Locke; the Arminian theologians alongside the orthodox Calvinist responses; the deists alongside the orthodox apologetic literature; the natural-religion writers alongside the revealed-religion defenders. The students were expected to write disputations defending positions Doddridge himself did not endorse, to debate among themselves on contested questions, to form judgments on the basis of the arguments rather than on the basis of authority. The pedagogical pattern produced a particular kind of educational outcome. The students were trained to think rather than to remember, to argue rather than to recite, to assess evidence rather than to accept assertions. The pattern would shortly produce, in the second generation of academy graduates, the intellectual habits that would supply much of the British scientific, industrial, and political reformist work of the late eighteenth and early nineteenth centuries.

The fourth feature was the practical orientation of the curriculum toward what its students would actually need to do. Oxford and Cambridge were, in the eighteenth century, principally institutions for the formation of Anglican clergy. Their curricula reflected this. The classical languages, scholastic philosophy, the theological framework of the established church — these were the operational subjects, taught in the operational form, that the universities' principal output (Anglican clergy) required. The dissenting academies could not assume that their output was principally clergy. Even Doddridge's academy at Northampton, where ministerial training was the founding purpose, produced graduates whose subsequent careers ran across the dissenting professions: ministry, certainly, but also medicine, education, commerce, and the broader range of occupations the dissenting communities were developing as their accommodation with the broader English social and economic order proceeded. Warrington Academy explicitly oriented its curriculum toward what its prospectus called "civil and active life" rather than ministry alone. The shift was operationally consequential. The curriculum the academies built was, by the design imposed on it by the actual occupational range of its graduates, a curriculum that worked across the broader range of educated occupations the eighteenth-century economy was producing.

The combination — English-language instruction, modern subjects, the dialectical pedagogy, the practical orientation — produced an educational pattern that the Oxford and Cambridge curricula of the same period did not produce. The graduates of the dissenting academies were prepared, in ways the Oxbridge graduates of the same generation were not, for the kind of work the rising commercial and industrial economy was creating. They could read the contemporary scientific literature in the languages it was being written in. They could conduct experiments rather than merely read about them. They could analyze economic and political questions through the new analytical apparatus the Scottish Enlightenment was producing. They could engage in argument with intellectual opponents and form judgments under conditions of intellectual disagreement. The educational pattern was, by accident of the religious-political exclusion that had created it, well-suited to the practical intellectual conditions of the late eighteenth century in ways that the

more conservative Oxbridge curriculum was not.

V. The Output

What the dissenting academies produced, across the eighteenth century, requires specification because the broader case Salomon's House has been tracking depends on registering what the parallel educational system actually generated. The output can be organized under several categories.

The first category was the dissenting ministry itself. The academies' founding purpose had been the training of dissenting clergy, and this purpose was carried out across the eighteenth century. Approximately several thousand dissenting ministers were trained at the various academies across the century — Doddridge at Northampton produced roughly one hundred forty graduates across his twenty-two-year tenure, the various academies of the second half of the century produced perhaps two or three hundred more, the New College at Hackney and the Manchester Academy continued the output into the early nineteenth century. The ministers staffed the Independent, Presbyterian (in its dissenting form, distinct from the Scottish Church of Scotland), Baptist, and eventually Unitarian congregations across England and Wales. They supplied, by the early nineteenth century, the religious leadership of a dissenting community that included approximately twenty to twenty-five percent of the English population by the time of the 1851 religious census.

The second category was the medical profession. The English medical profession of the eighteenth century was organized around the Royal College of Physicians (which required Oxford or Cambridge medical degrees for full membership) and the Royal College of Surgeons (which operated by apprenticeship). Dissenting families whose sons were destined for medicine could not, by the religious tests, qualify for the College of Physicians' membership. They sent their sons to Edinburgh, Glasgow, and Leiden for medical degrees that were operationally respected even where they did not produce London membership; many of those sons attended a dissenting academy first, completing the academy's general course before proceeding to the university for medical specialization. Thomas Percival, who graduated from Warrington Academy as one of its first students in the early 1760s, went to Edinburgh for his medical degree, returned to Manchester, and founded the Manchester Literary and Philosophical Society in 1781. The pattern — dissenting academy preparation, Scottish or Dutch medical degree, subsequent practice in the provincial English cities where dissenting medical practitioners were welcome — produced a medical class whose intellectual formation was distinct from the Oxbridge medical formation and whose subsequent contributions to medical practice and research were operationally important.

The third category was the technical and scientific leadership of the rising industrial economy. This is the category that matters most for the case Salomon's House is tracking, and the specific examples deserve registration. Joseph Priestley's discovery of oxygen in 1774, conducted across his

subsequent ministry at Leeds and at Lord Shelburne's Wiltshire estate at Bowood, was the work of a man whose intellectual formation had been Daventry Academy and Warrington Academy and whose institutional connections ran through the dissenting educational network. John Dalton, who developed atomic theory across his Manchester work in the early nineteenth century, had been trained partly in the dissenting educational tradition that had reached Manchester through the Warrington succession. The Manchester Lit and Phil under Percival from 1781, the Birmingham Lunar Society in which Priestley participated across the 1780s, the Newcastle Literary and Philosophical Society from 1793, the broader provincial scientific institutional life that Part IV will examine — these were institutions whose memberships were heavily drawn from the dissenting communities and from the graduates of the dissenting educational tradition.

The industrial entrepreneurs themselves were not, in most cases, academy graduates in the formal sense — Wedgwood, James Watt, Matthew Boulton, Richard Arkwright did not attend the dissenting academies, though several of them were from dissenting backgrounds and Wedgwood had close personal connections with the academy network through his friendship with Priestley. What the academies produced for the industrial entrepreneurs was the technical and scientific support network that their work required. The chemists who supplied them with information about dyes and glazes and metallurgy. The mathematicians who could analyze their mechanical systems. The natural philosophers who could conduct the experimental investigations their commercial work required. The educated commercial and managerial class who could operate their enterprises at the scale the new economy required. The academies trained, by the design of their curriculum and by the accident of who their graduates were, the specific technical workforce that the industrial revolution would require.

The fourth category was the intellectual and political leadership of the broader dissenting community. The political reform movements of the late eighteenth and early nineteenth centuries — the agitation for repeal of the Test and Corporation Acts, the campaigns against the slave trade and slavery, the parliamentary reform movement that produced the Reform Act of 1832, the broader configuration of Whig and Liberal political culture that the dissenting communities supported across the nineteenth century — were substantially staffed by men whose intellectual formation had been the dissenting academies. The educational pattern Doddridge had built, with its dialectical pedagogy and its emphasis on critical assessment of competing positions, produced citizens who were operationally capable of political argument and political mobilization in ways the more traditional Oxbridge formation did not. The academies were, by the early nineteenth century, the educational foundation of much of British liberalism.

The output, taken in aggregate, was operationally significant in ways the original exclusion of 1662 had not anticipated. The Restoration Anglican settlement had intended to consolidate religious uniformity by excluding the dissenters from the established institutional life. The consequence was the production of a parallel educational system whose curricular innovations would shortly produce,

across the eighteenth century, much of the technical and intellectual leadership of the rising industrial economy. The institutional configuration the case is tracking included, by the late eighteenth century, this parallel system alongside the Royal Society's central apparatus. The two operated in conversation. The dissenting academies' graduates entered the Royal Society's fellowship in increasing numbers across the second half of the eighteenth century — Priestley was elected a Fellow in 1766 and received the Society's Copley Medal in 1772 for his electrical work; Dalton would be elected in 1822; Thomas Percival was elected in 1765 and conducted his Manchester Lit and Phil work in conscious connection with the Royal Society's broader institutional life. The central apparatus and the parallel educational system were operationally integrated even where their formal institutional structures remained distinct.

VI. What the Exclusion Had Produced

The structural feature of what the exclusion of 1662 had produced deserves to be named specifically because the rest of this case will continue to register its operational consequences.

The exclusion had not been intended to produce a competing educational system whose intellectual standards would shortly equal or exceed those of the established universities. It had been intended to consolidate Anglican religious uniformity by removing from the established institutional life those who would not subscribe to the Anglican settlement. The intention had not produced its desired result; the dissenting communities had not, across the half-century following 1662, been absorbed into the established church or driven into religious silence. The communities had instead built the institutional infrastructure required for their continued existence as functioning religious bodies, with their own clergy training, their own educated laity, their own publication networks, their own intellectual culture. The infrastructure had been built under conditions of legal disability that limited what it could accomplish. The infrastructure had nonetheless been built. And the curricular innovations that the infrastructure had developed across the eighteenth century — innovations that the established universities had no need to develop, because their position within the established religious-political settlement protected them from the operational pressure that drove the dissenting academies' pedagogical experimentation — had produced an educational pattern that was, by the second half of the eighteenth century, operationally better suited to the conditions of the rising industrial economy than the Oxbridge pattern was.

The historical irony is worth registering. The Restoration Anglican settlement had been designed by men who understood themselves as protecting the religious and political stability of the English state against the threat the dissenters represented. The protection had been operationally successful within the religious-political domain it had targeted. The dissenters were excluded from offices of state, from the universities, from municipal corporations, from the parish ministry of the established church. What the protection had not anticipated was the consequence of forcing the excluded population to build its own institutional infrastructure under conditions that produced

curricular innovations the protected institutions did not need to undertake. The exclusion had produced, by accident of its operational consequences, a parallel system whose innovations would shortly be operationally consequential at the level of the broader English economic and intellectual life. The protected universities — Oxford, Cambridge — had remained at their inherited curricular pattern through the eighteenth century, producing graduates well-formed for the Anglican ministry and the traditional professions but poorly formed for the new occupations the industrial economy was producing. The unprotected academies, forced by their structural disability to find an institutional pattern that could operate without the resources and the prestige the universities possessed, had produced an educational form that worked across the broader range of occupations the new economy required.

The point is structurally important for the broader trajectory the case is tracking. The institutional configuration that supports cumulative scientific and technical work does not develop through a single institutional channel. It develops through the configuration of multiple channels operating in conversation with each other — the central institution that captures and transmits the foundational work, the educational system that trains the next generation of practitioners, the patronage networks that support the work, the publication apparatus that preserves it, the cultural standing that recruits talented men into the configuration. The Royal Society had supplied, across the late seventeenth and early eighteenth centuries, the central institutional capture that Part II tracked. What the dissenting academies supplied across the eighteenth century was the educational system that produced the practitioners. Neither institutional channel alone would have produced what the configuration accomplished. The two together — the Royal Society at the central capture, the dissenting academies at the educational supply, each operating with its specific institutional logic and its specific structural advantages — produced the configuration that would shortly generate the world's first industrial economy.

The next Part will examine the third major institutional channel that emerged across the same period: the provincial scientific societies in which the technical work of the industrial economy was being conducted in immediate proximity to the men who were actually building the new factories, the new chemical processes, the new mechanical systems, the new commercial enterprises. The Royal Society had supplied the central capture. The dissenting academies had supplied the educational system. The provincial societies would shortly supply the institutional mechanism through which scientific knowledge and industrial practice would be actively integrated at the level of daily working life. The configuration the case is tracking was, by 1770, operating across all three channels simultaneously. What the three together produced is what the case will examine in the parts that follow.

Part IV — The Provincial Societies and the Industrial Integration

I. The Third Channel

The configuration the case has been tracking had developed, by the middle of the eighteenth century, two operational institutional channels. The Royal Society in London supplied the central capture and transmission of natural-philosophical work — weekly meetings, *Philosophical Transactions*, the Continental correspondence network, the institutional defense of priority claims, the cultural prestige that drew talented men into the configuration. The dissenting academies across England supplied the educational system through which the next generation of natural philosophers, physicians, ministers, and educated middle-class men were being formed in a curricular pattern adapted to the intellectual conditions of the contemporary economy. The two channels operated in conversation. Academy graduates were elected to Royal Society Fellowships. Royal Society Fellows corresponded with academy tutors. The institutional memory the case has been describing was being maintained through both channels simultaneously, with each supplying what the other was not built to supply.

What was missing, in the mid-eighteenth-century configuration, was the institutional mechanism through which the work being conducted in the Royal Society's London-centered apparatus and through which the men being trained in the dissenting academies' educational system would be connected to the practical industrial and commercial work that the rising English economy was actually conducting. The Royal Society was a London institution. Its membership was drawn principally from the metropolitan educated elite — the gentry, the clergy, the professionals, the wealthier merchants. Its meetings were weekly affairs at Crane Court whose attendees lived in or visited the capital. The natural-philosophical work the Society captured was being conducted, in many specific cases, in the laboratories and observatories of London and the nearby home counties; the dispersed provincial work that was being conducted at the actual sites where the new industries were emerging — Birmingham, Manchester, Newcastle, Sheffield, the Cornish mining districts, the Scottish industrial centers — was reaching the London apparatus only through the personal correspondence of individual Fellows or through occasional published reports.

The institutional channel through which the provincial industrial work was integrated with the broader natural-philosophical configuration emerged across the second half of the eighteenth century in a particular institutional form. The form was the local scientific society, organized in each of the major provincial centers by a combination of local manufacturers, physicians, dissenting

ministers, and educated gentry, meeting at intervals for the demonstration of experimental work, the discussion of practical industrial problems, and the cultivation of the social network that the broader configuration required. The provincial society was not, in its structural features, a copy of the Royal Society. It operated at a smaller scale. Its membership combined working scientists with industrial entrepreneurs in proportions the metropolitan institution did not match. Its agenda ran across the immediate practical questions that the local industrial economy was generating alongside the broader natural-philosophical questions that the metropolitan institutions were addressing. The provincial society supplied the institutional mechanism through which scientific knowledge and industrial practice were being actively integrated at the level of daily working life.

The most operationally consequential of these provincial institutions was the Lunar Society of Birmingham. The Society's institutional structure was minimal — fewer than fourteen core members at any time, no formal charter, no permanent meeting hall, no published proceedings of its own — but the operational consequences of its work would shape the industrial economy of the late eighteenth century in ways the Royal Society's metropolitan apparatus did not match. The case begins with the Lunar Society because the operational pattern the Society demonstrated was the pattern the other provincial institutions would shortly elaborate.

II. The Lunar Society of Birmingham

Birmingham in the 1760s was a town of approximately thirty thousand people, growing rapidly through the expansion of the metal-working trades that had concentrated in the region since the late seventeenth century. The town was not a chartered borough; it returned no Members of Parliament; it had no university and no cathedral. What it had was a population of small manufacturers — buckle-makers, button-makers, gun-makers, the broader "toy" trades that produced the small metal goods the period's broader economy required — operating in workshops scattered across the town and the surrounding industrial districts. The dissenting community was sizeable. The Lunar Society's membership would draw heavily from the dissenting families of the region whose intellectual formation had been in the academy network the previous Part traced.

The Society had no fixed founding date. The institutional genealogy traces back to the friendship between Erasmus Darwin, a physician practicing at Lichfield since 1756, and Matthew Boulton, a Birmingham manufacturer who had inherited his father's metal-working business and had begun, in the early 1760s, the development of the Soho Manufactory at Handsworth that would shortly become one of the operational centers of the English industrial economy. Darwin and Boulton had begun meeting socially and intellectually in the early 1760s, with the meetings expanding across the decade to include additional figures whose interests intersected at the boundary between natural-philosophical work and industrial application. By 1765 the group had begun to refer to itself as the Lunar Circle, with the meetings scheduled for the Monday nearest the full moon — a practical accommodation to the absence of street lighting in the eighteenth-century

industrial districts, where the members traveled between meetings on horseback or by carriage and required moonlight for the return journey. The name "Lunar Society" became the formal designation by 1775, by which point the membership and the meeting pattern had stabilized into the institutional form that would operate across the following four decades.

The core membership across the Society's operational period included the major figures whose work the period would shortly produce. Erasmus Darwin, the Lichfield physician, was the Society's senior figure across its early years — a wide-ranging intellectual with interests across botany, geology, mechanical invention, and the broader range of natural-philosophical work, whose poetic and philosophical writings (*The Botanic Garden* of 1789 and 1791, *Zoonomia* of 1794 to 1796 with its anticipations of evolutionary theory that his grandson Charles would shortly carry forward) supplied much of the period's most ambitious natural-philosophical synthesis. Matthew Boulton, the Birmingham manufacturer, supplied the operational center at Soho House where the meetings were principally held; his manufactory employed approximately a thousand workers by the 1780s and was producing buttons, buckles, silver plate, ornamental metalwork, coinage (after Boulton acquired the Royal Mint's coinage contract in 1788), and from 1775 the steam engines that the Boulton-Watt partnership would shortly distribute across the English industrial economy. Josiah Wedgwood, the potter operating at Burslem and from 1769 at the new Etruria works he had purpose-built for the production of ornamental ceramics, was a regular correspondent and frequent visitor whose chemical and industrial interests connected the Lunar Society's work to the broader Staffordshire pottery industry that he had largely transformed across the 1760s and 1770s. James Watt, the Scottish engineer who had developed the separate condenser steam engine at Glasgow in 1765 and had patented it in 1769, moved to Birmingham in 1774 to enter the partnership with Boulton that would shortly produce the most operationally consequential industrial technology of the eighteenth century. Joseph Priestley, the Warrington-trained natural philosopher whose Part III career has been traced, joined the Society in 1780 when he moved to Birmingham to take the ministry of the New Meeting Unitarian congregation. William Withering, a physician practicing at Birmingham from 1775, conducted the botanical and pharmacological investigations that produced his *An Account of the Foxglove* in 1785 and supplied the medical use of digitalis for cardiac conditions that would be the foundation of subsequent cardiac pharmacology. James Keir, a Scottish-trained chemist whose translation of Macquer's *Dictionnaire de Chymie* had appeared in 1771, conducted at Tipton from 1780 the industrial alkali manufacture that supplied the soap and glass industries of the broader region.

Additional figures circulated through the Society's meetings across the operational period. Samuel Galton Junior, the Quaker gunmaker and naturalist, joined the Society in 1781. William Murdoch, Watt's engineer at Boulton and Watt's Cornish operations and the developer of coal-gas lighting, was a peripheral but regular participant from the late 1770s. John Whitehurst, the Derby clockmaker and geologist whose *Inquiry into the Original State and Formation of the Earth* of 1778 supplied one of the period's foundational geological texts, was a regular member. Richard Lovell

Edgeworth, the Anglo-Irish educational theorist and inventor, attended meetings when in the Midlands. Thomas Day, the educational writer who would produce *Sandford and Merton*, attended in the same way. Anna Seward, the Lichfield poet, was on the social periphery of the circle without formal Society membership. The Quaker merchant John Wilkinson, whose ironworks at Bradley supplied much of the cast-iron production that the Boulton-Watt engines required, was a regular correspondent. Joseph Wright of Derby, the painter whose canvases registered the visual culture of the period's industrial and natural-philosophical work — *An Experiment on a Bird in the Air Pump* of 1768, *A Philosopher Giving That Lecture on the Orrery* of approximately 1766 — circulated through the Society's social network.

The Society's meetings were not weekly. The monthly pattern — one Monday a month, timed to the full moon — produced approximately twelve meetings a year, conducted at Boulton's Soho House, at Darwin's Lichfield residence (and after Darwin's move to Derby in 1781 at Derby), at Wedgwood's Etruria, or at Great Barr Hall (Galton's residence after 1781). The meetings began with afternoon tea, ran through a long dinner with generous wine, and continued in conversation until late evening. The agenda was informal. Members presented experimental work in progress, demonstrated new mechanical or chemical processes, discussed the practical industrial problems they were currently engaged with, debated the philosophical and political questions of the period. The minutes were not formally recorded; what survives of the meetings' content is reconstructed from members' personal correspondence, from references in their published work, and from the various memoirs and biographies that subsequent generations produced.

What the Society produced, in operational terms, was the institutional mechanism through which the major industrial innovations of the late eighteenth century were developed in conversation among the men who were actually conducting the work. The clearest case is the Boulton-Watt steam engine partnership, which the Society's institutional framework largely organized.

III. The Steam Engine and the Society's Operational Reach

James Watt had developed the separate condenser steam engine at Glasgow across 1764 and 1765, working as instrument-maker to the University and as friend to Joseph Black, the chemist who had developed the concept of latent heat that supplied the theoretical foundation for Watt's mechanical insight. The Newcomen atmospheric engine, in use across the English mining industry since 1712 for the pumping of water from coal mines, operated by alternately heating and cooling its single cylinder — injecting cold water to condense the steam and create a vacuum, then reheating to admit fresh steam. The process wasted enormous quantities of fuel because the cylinder itself had to be reheated after each stroke. Watt's insight, in 1765, was that the condensation could be conducted in a separate vessel maintained continuously cool while the working cylinder was maintained continuously hot, eliminating the wasteful reheating cycle. The thermodynamic principle was correct. Implementing it in a working engine, however, required engineering work at a scale Watt could not conduct without financial backing.

The early backing came from John Roebuck, the proprietor of the Carron Ironworks near Falkirk, who agreed in 1768 to underwrite Watt's experimental work in exchange for two-thirds of the prospective patent. Watt patented the separate condenser in January 1769 — Patent 913, "A New Invented Method of Lessening the Consumption of Steam and Fuel in Fire Engines." The Roebuck partnership did not produce a working engine. The prototype built at Kinneil House in Stirlingshire across 1769 to 1773 demonstrated the principle but did not achieve the operational reliability commercial deployment required. Roebuck's broader financial difficulties — his coal-mining and ironworks operations had been struggling — produced his bankruptcy in 1773. His share of the patent was held by his creditors, principally Matthew Boulton, who had been corresponding with Watt across the previous several years through Joseph Black's introduction.

Boulton acquired Roebuck's share of the patent in 1774 and persuaded Watt to relocate from Glasgow to Birmingham to enter the partnership that would shortly be Boulton and Watt. The relocation was institutionally significant. Birmingham supplied Watt with what Glasgow could not: a manufacturing center with the metalworking capacity required for the production of precise cylinders and pistons, the financial backing required for the development work, and the broader scientific network that the Lunar Society's institutional framework supplied. The partnership petitioned Parliament in 1775 to extend the original 1769 patent for an additional twenty-five years, on the grounds that the engineering work required to bring the invention to commercial scale had consumed the original patent's operational duration without producing the commercial returns the inventor had been promised. Parliament granted the extension in the Steam Engine Act of 1775, vesting in Watt "the sole use and property of certain steam engines of his invention, throughout the majesty's dominions" until 1800.

The protection mattered. The patent extension gave Boulton and Watt a twenty-five-year monopoly on the most operationally consequential industrial technology of the period. Their partnership operated, across the period from 1775 to 1800, on a license-royalty model: Boulton and Watt sold no engines outright but licensed their construction to mining and manufacturing concerns in exchange for one-third of the fuel savings the engines produced compared to the older Newcomen design. By 1800, when the patent expired, approximately five hundred Boulton-Watt engines were in operation across the British industrial economy — pumping water from Cornish tin mines, driving rolling mills at the Wilkinson ironworks, providing rotary motion to the cotton spinning mills that Arkwright and his successors had developed across the Lancashire and Cheshire regions, supplying mechanical power to the broader range of industrial operations that the new technology had made operationally feasible. The partnership had produced large personal fortunes for both men. The engines had supplied the mechanical power foundation of the industrial economy that the period was producing.

The Lunar Society's institutional role in this development requires specific registration. The technical work was conducted by Watt at Soho. The financial and managerial work was conducted by Boulton. The supporting engineering work — the precision boring of cylinders to the tolerances Watt's design required — was conducted at John Wilkinson's ironworks at Bradley and Bersham, where Wilkinson's cannon-boring technology (patented 1774) supplied the only manufacturing process in Britain capable of producing cylinders to Watt's specifications. The chemical and metallurgical questions that arose in the engine's development were debated at Lunar Society meetings, with Priestley, Keir, and the broader chemical membership contributing experimental and theoretical work. The mechanical problems were addressed in conversations with Wedgwood and the other industrial members whose practical experience supplied relevant comparison cases. Watt corresponded extensively with Joseph Black at Glasgow on the thermodynamic principles. The institutional configuration in which the engine's development was being conducted included the Lunar Society's meetings at the operational center, the broader correspondence network the Society's members maintained with their Continental and Scottish contemporaries, and the practical industrial connections through which the engineering work was being executed.

What the configuration produced was not merely an invention. It was an industrial system. The Boulton-Watt engines were sold not as standalone machines but as integrated power systems whose installation and operation required the technical expertise the partnership supplied through its engineers. William Murdoch, who joined the partnership in 1777 as one of its principal engineers, traveled across the Cornish mining districts installing engines and supervising their operation. The Cornish license-royalty arrangements produced the sizeable cash flows that financed the partnership's operations across the 1780s and 1790s. The training of additional engineers at the Soho works produced a generation of mechanical engineers — Murdoch, John Southern, James Watt Junior, the broader cohort — whose subsequent work would shortly carry the steam-engine technology into the railway applications of the early nineteenth century. The institutional pattern the

Lunar Society had supplied was the pattern through which a specific natural-philosophical insight (the separation of condensation from the working cylinder) had been converted, across approximately a quarter century, into the foundational power technology of the industrial economy.

The conversion required all the institutional elements operating together. Watt's mechanical work alone would not have produced the engines without Boulton's financial backing. Boulton's capital alone would not have produced the engines without Watt's technical work. Neither of them, working separately, would have produced the system that the Lunar Society's broader institutional framework had supplied. The institutional capture this case has been tracking included, by the 1780s, the operational mechanism through which natural-philosophical work could be converted into industrial application at commercial scale, conducted in a network of working scientists and industrial entrepreneurs whose regular institutional meetings sustained the configuration across the long timeframes the work required.

IV. The Other Provincial Centers

Birmingham was not the only English provincial center to develop institutional infrastructure of this kind across the same period. The pattern the Lunar Society had demonstrated was reproduced, with local variations, in several other major industrial centers across the late eighteenth century.

The Manchester Literary and Philosophical Society was founded in February 1781. Its founding members included Thomas Percival, the Warrington Academy graduate whose Edinburgh medical degree had been followed by practice at Manchester since 1767; Thomas Henry, a Manchester apothecary and Fellow of the Royal Society whose chemical and bleaching work was operationally connected to the cotton industry of the region; Thomas Barnes, a Unitarian minister; and a broader founding membership of approximately fifty figures drawn from the medical, educational, and manufacturing communities of the region. The Society met fortnightly at first, monthly later, with papers presented on natural-philosophical and practical industrial subjects. *Memoirs of the Literary and Philosophical Society of Manchester* began publication in 1785 and would continue across the following two centuries, supplying the published record of work that included John Dalton's atomic theory papers of the first decade of the nineteenth century, Joule's thermodynamic work of the 1840s, and the broader range of Manchester scientific and industrial investigation across the period the Society's operational life spanned. The Society's principal long-term institutional achievement was the founding, in 1786, of the Manchester Academy that would become the institutional inheritor of Warrington Academy's educational tradition after Warrington's dissolution in the same year. The Society and the Academy operated as institutional partners across the late eighteenth and early nineteenth centuries, with overlapping memberships, shared premises in some periods, and the institutional integration of scientific work with educational provision that the regional configuration required.

The Newcastle Literary and Philosophical Society was founded in February 1793 by William Turner, a Unitarian minister whose intellectual formation had been at Warrington Academy. The Society's founding membership of approximately forty figures included physicians, manufacturers, clergy, and educated gentry of the Newcastle region whose interests connected to the coal mining, glass manufacturing, and chemical industries that the area was producing. The Society's library would shortly become one of the major scientific collections of the north of England, with approximately eight thousand volumes by 1820 and approximately twenty thousand by 1850. The Society's meeting rooms would house, across the early nineteenth century, the lectures of Robert Stephenson and George Stephenson whose railway engineering work was being conducted in the Newcastle region across the 1820s. The Society's institutional contribution to the development of railway technology — the work that would shortly produce the Stockton and Darlington Railway of 1825 and the Liverpool and Manchester Railway of 1830 — operated through the same pattern the Lunar Society had demonstrated in the steam engine: working engineers in regular institutional contact with the broader natural-philosophical community whose theoretical and practical knowledge their engineering work required.

The Bristol Philosophical and Literary Society had operated in the 1690s and 1730s in various proto-institutional forms before its formal constitution in 1819 as the Bristol Philosophical Institution. The Derby Philosophical Society was founded by Erasmus Darwin in 1783 after his move from Lichfield to Derby; it operated as essentially a regional extension of the Lunar Society's institutional pattern. The Liverpool Royal Institution was founded in 1814. The Leeds Philosophical and Literary Society in 1819. The Sheffield Literary and Philosophical Society in 1822. The Hull Literary and Philosophical Society in 1822. The pattern by the early nineteenth century was general: every major English provincial city had developed, or was in process of developing, a local scientific society whose institutional structure followed the pattern Birmingham and Manchester had supplied at the founding moment. The configuration the case is tracking now operated, by approximately 1820, through a network of dozens of provincial societies operating in conversation with each other and with the metropolitan Royal Society apparatus.

The institutional logic that drove this multiplication deserves specification. Each provincial society had been founded by local figures whose intellectual interests and industrial work required the institutional infrastructure that the metropolitan Royal Society did not supply at the regional scale. The members of the Manchester Lit and Phil could not, in operational terms, attend Royal Society meetings at Crane Court without expensive travel and significant time away from their working operations. The communication that the metropolitan apparatus supplied through *Philosophical Transactions* was operationally useful but did not substitute for the face-to-face institutional contact that the regional members required for the working conversations their industrial and natural-philosophical work demanded. The provincial society supplied the regional institutional infrastructure that the metropolitan structure could not supply. Once one provincial society had demonstrated the institutional pattern, the pattern reproduced across the other regional

centers because the operational logic was generalizable. Every major industrial center required the configuration the Birmingham and Manchester foundations had supplied. The configuration was duly built.

The aggregate institutional capacity by the early nineteenth century registered the structural transformation. The Royal Society in London continued to operate as the central institution. The provincial societies operated as regional institutions whose members corresponded with each other, attended each other's meetings when they could, and contributed papers to each other's publications. The dissenting academies continued to operate as the principal educational infrastructure. The aggregate produced a national institutional configuration that no other European country had developed to the same density and that supplied, in operational terms, the institutional foundation of what would shortly be the world's first industrial economy. The configuration was not centrally planned. It had emerged across approximately seventy-five years through the institutional decisions of successive generations of natural philosophers, industrialists, and educated gentry whose individual choices to build local institutions where the central institution did not reach had produced, in aggregate, the institutional density that the broader development required.

V. Banks at the Apex

The figure who occupied the central institutional position across the period of the provincial societies' formation was Joseph Banks, who held the Presidency of the Royal Society from November 1778 until his death in June 1820 — forty-one years of continuous tenure, by far the longest in the institution's history and a tenure under which the Royal Society's operational character was shaped in ways that would persist into the nineteenth century.

Banks had been born in 1743, the only son of a wealthy Lincolnshire landowning family. He had been educated at Harrow, Eton, and Christ Church Oxford, where he had pursued botanical interests at his own initiative when the university could not supply formal instruction in the subject. He had inherited the family estate at Revesby Abbey in his early twenties, providing him with an income of approximately six thousand pounds a year that placed him among the wealthiest private individuals in England and supplied the material foundation for his subsequent career as scientific patron and explorer. His first major scientific expedition had been to Newfoundland and Labrador in 1766 as an independent naturalist. His second had been the Cook voyage on the *Endeavour* from 1768 to 1771, on which he had spent approximately ten thousand pounds of his own funds — equivalent to the better part of two years of his income — to underwrite a scientific contingent of eight assistants, artists, and servants whose collective work produced one of the most operationally consequential natural-history collections of the eighteenth century. His return to London in July 1771 had made him immediately famous in the broader London social and intellectual world.

The position Banks settled into across the 1770s combined personal wealth, scientific accomplishment, social standing, and political connection in a configuration the period had not previously seen. He moved his London household to 32 Soho Square in 1776, where his library and his natural-history collections would grow across the following four decades into one of the principal scientific resources of the English-speaking world. The Soho Square house became, by the 1780s, the operational meeting place of much of London's scientific community; the breakfasts Banks hosted there on weekly schedules drew the broader range of the natural-philosophical community for conversation, the consultation of his library, and the exchange of intelligence on Continental and colonial scientific work. King George III appointed him informal director of the Royal Botanic Gardens at Kew in 1773; the position was formalized in 1797. Banks's relationship with the king developed into one of personal friendship, conducted through their shared interest in agricultural improvement, botanical exploration, and the broader range of natural-philosophical work that the period was producing. He was made a baronet in 1781, a Knight Commander of the Bath in 1795, and a Privy Councillor in 1797. The combination — wealth, scientific standing, royal favor, and political connection — placed him in a position no English natural philosopher had previously occupied and from which he conducted the Royal Society's Presidency for forty-one years.

What Banks did with the Presidency requires specific description. He was, by the institutional standards of the period, an unusually active President. He chaired the Society's meetings personally, with limited exceptions, across his entire forty-one-year tenure. He directed the Society's affairs through detailed personal involvement in the election of Fellows, the selection of officers, the management of the Society's finances, and the day-to-day operations of the Society's secretariat. He used the Presidency to coordinate the broader institutional configuration that this case has been tracking, supplying the central node through which the various components of the configuration — the provincial societies, the dissenting academies, the colonial and Continental scientific networks, the major industrial enterprises — were connected through correspondence, mutual visits, shared projects, and the broader patterns of institutional interaction that the period's natural-philosophical work required.

The specific institutional activities Banks conducted from the Royal Society Presidency and the Soho Square headquarters can be specified. He directed Kew Gardens across the period of its development from a royal pleasure-garden into the world's principal botanical research institution, sending plant collectors across the British colonies and the broader globe — Francis Masson to South Africa, James Bowie and Allan Cunningham to Brazil and Australia, Archibald Menzies on Vancouver's Pacific expedition, the broader cohort of approximately thirty botanical collectors whose work supplied Kew with the comprehensive global plant collection that the institution accumulated across Banks's forty-seven-year directorship. He served as the trustee of the British Museum responsible for the natural-history collections, supplying the institutional connection between the Royal Society's apparatus and the broader national collections that the period was

developing. He supplied the institutional connection to the East India Company's operations in India, advising the Company on the introduction of tea cultivation, the development of botanical gardens at Calcutta and elsewhere, and the broader integration of the scientific work the Company was conducting with the metropolitan institutional apparatus. He served as adviser to the British government on the establishment of the New South Wales colony in 1788 and on the subsequent development of Australian agriculture, supplying the institutional connection between scientific work and colonial policy. He founded the African Association in 1788, the precursor of the Royal Geographical Society, to coordinate the exploration of the African continent's interior. He fostered the Linnean Society of London, founded in 1788 by James Edward Smith with Banks's patronage, as the specialist institution for botanical and zoological work that the Royal Society's broader agenda could not adequately accommodate. He supplied financial and institutional support for William Smith's geological survey of England across the early years of the nineteenth century, producing the first geological map of an entire country.

The institutional pattern Banks operated was, in its specific structure, the operational center of the broader configuration. The Royal Society was the central institution. The Linnean Society and the subsequent specialist institutions (the Geological Society of 1807, the Astronomical Society of 1820) were the disciplinary specializations the central institution could not maintain at the required depth. Kew was the botanical research center. The British Museum was the national collection. The colonial scientific operations supplied the geographic reach. The provincial societies supplied the regional integration with industrial work. Banks at Soho Square supplied the personal node through which all of these institutional components were coordinated across the period from 1778 to 1820. The configuration was not formal. There was no organizational chart and no central administrative authority. The configuration operated through the personal correspondence Banks maintained, the personal visits he conducted, the personal favors he distributed and received, the personal connections he cultivated across the relevant institutional figures. The institutional memory the case has been tracking was, by the end of Banks's Presidency, being maintained through an apparatus whose operational center was one man's house at 32 Soho Square and one man's continuous personal labor across four decades.

Banks's death in June 1820 produced the operational question that the configuration would shortly have to address. The institutional center could not, in its existing form, be reproduced without the specific personal characteristics — the wealth, the social standing, the royal connection, the personal energy — that Banks had supplied. The configuration would shortly require institutional reform that would distribute the central coordination across multiple organizations rather than concentrating it in a single personal node. The reform would emerge across the 1820s and 1830s through the founding of the British Association for the Advancement of Science (1831), the institutional reforms at the Royal Society itself across the same period, and the broader institutional multiplication that Part V will examine.

What Banks's Presidency had accomplished, however, was the integration of the various institutional components the case has been tracking into an operationally coherent national scientific apparatus. By 1820 the configuration operated, in working terms, as a national institution. The provincial societies were institutionally integrated with the metropolitan Royal Society apparatus. The dissenting academies were institutionally integrated with both. The colonial scientific operations were institutionally integrated with all three. The industrial work of Birmingham, Manchester, Newcastle, and the other industrial centers was institutionally integrated with the broader scientific apparatus through the provincial societies' membership and through the personal connections the Lunar Society and its successor institutions had established. The configuration was, by Banks's death, the densest national scientific apparatus in Europe.

VI. The Patent System and the Capital Markets

Two additional institutional features deserve specification at the close of Part IV because the configuration the case is tracking required both for its operational completion. Neither the patent system nor the capital markets were scientific institutions in the formal sense. Both supplied the institutional infrastructure through which the scientific and technological work the case has been tracking was being translated into commercial application at industrial scale.

The English patent system in the late eighteenth century operated under the Statute of Monopolies of 1624, which had supplied the legal foundation for patents of invention while restricting most other forms of royal monopoly grant. The Statute permitted the Crown to grant exclusive rights to "the true and first inventor" of "any manner of new manufactures" for a period of fourteen years. The system as it had developed across the seventeenth and eighteenth centuries was bureaucratically cumbersome — patent applications had to pass through approximately twenty separate administrative stages and could cost over a hundred pounds in fees, putting the system out of reach for poorer inventors — but it supplied legal protection for the inventions of the wealthier or better-connected inventors who could afford the process. Watt's separate-condenser patent of 1769 has been described in this Part. Wilkinson's cannon-boring patent of 1774. Arkwright's water-frame patent of 1769. Crompton's spinning mule, developed in the late 1770s, was not patented (Crompton lacked the financial resources to pursue the application) and Crompton lost the commercial benefits of his work to subsequent unauthorized adopters — supplying, by negative example, the institutional importance the patent system had acquired by the period. The Statute of Monopolies' fourteen-year protection was supplemented in specific cases by parliamentary extension, as in the 1775 Steam Engine Act that extended Watt's patent by twenty-five years. The aggregate effect of the patent system was to supply the legal protection that converted the inventor's intellectual work into a commercially valuable property whose returns could be realized across the period of the patent's protection. The system was imperfect — the bureaucratic cumbersomeness produced significant losses to inventors whose resources could not navigate the administrative apparatus —

but it operated, across the period this Part has been tracking, as one of the institutional foundations of what the configuration was producing.

The capital markets of the City of London supplied the financial infrastructure through which the commercial development of new industrial technologies was conducted. London had developed across the late seventeenth and eighteenth centuries as the principal financial center of Europe, with the Bank of England (founded 1694), the stock exchange (operating informally from the 1690s and formally chartered in 1801), the insurance markets centered on Lloyd's (operating from the 1680s), and the broader banking and commercial credit infrastructure that the City's commercial development had produced. The capital available through this infrastructure was considerable. The Boulton-Watt partnership's working capital had been supplied through Boulton's personal credit, through Wedgwood's family resources, and through the broader connections that the Lunar Society's membership had supplied. The cotton mills of Lancashire had been financed through a combination of partnership capital from the manufacturing families themselves, regional banking connections, and the broader London commercial credit network. The canal building of the late eighteenth century — the Bridgewater Canal opened in 1761, the Trent and Mersey Canal completed in 1777, the Grand Trunk system of the 1770s and 1780s, the broader network of approximately four thousand miles of canals built across the period — had been financed through subscription companies whose share capital was raised through the London markets. The railway construction of the early nineteenth century would shortly be financed through the same institutional infrastructure at much larger scale.

What the patent system and the capital markets supplied, in operational terms, was the institutional bridge between the scientific and technological work and the commercial application. An invention without patent protection produced limited commercial returns to its inventor and limited incentive for continued investment in the development work. A commercial venture without capital could not scale to the operational size the industrial economy required. The configuration the case has been tracking included, by the end of the eighteenth century, both of these institutional bridges alongside the scientific institutions themselves. The Royal Society captured the scientific work. The dissenting academies trained the practitioners. The provincial societies integrated the scientific work with industrial practice. The patent system supplied the legal protection for the inventions. The capital markets supplied the financing for the commercial deployment. The configuration was operationally complete.

What the configuration produced, taken in aggregate, was the world's first industrial economy. The point should be registered without softening it. The industrial revolution that emerged in Britain across the late eighteenth and early nineteenth centuries was not the work of individual inventors operating in isolation, however much the conventional historiography has emphasized the inventors as the visible figures. The revolution was the work of an institutional configuration whose specific components had been built across approximately one hundred and seventy years from Bacon's *New*

Atlantis of 1627 forward — the Royal Society at the central capture, the dissenting academies at the educational system, the provincial societies at the regional integration with industrial practice, the patent system at the legal protection, the capital markets at the financing, Banks at the personal coordinating center across the apex period. The configuration produced what it produced because each of its components supplied something the others could not. The aggregate operated at a density and scale that no other contemporary European country had achieved. The industrial revolution was the operational consequence of the institutional configuration.

The next Part will examine what happened to the configuration across the period from approximately 1820 to 1859 — the period of the institutional multiplication that produced the British Association for the Advancement of Science, the mechanics' institutes, the Royal Institution's full operational development under Davy and Faraday, the specialist societies of the early nineteenth century, and the broader institutional ecology within which Charles Darwin would conduct, across his twenty years of work between the *Beagle* return in 1836 and the publication of *On the Origin of Species* in 1859, what the institutional configuration would shortly register as the most operationally consequential single scientific work of the century.

Part V — The Nineteenth-Century Institutional Multiplication

I. The Situation in 1820

Joseph Banks died at Spring Grove on June 19, 1820, in his seventy-eighth year and the forty-second year of his Royal Society Presidency. The institutional configuration he had coordinated through his Soho Square correspondence and his personal labor across four decades passed, at his death, into a transitional period whose specific features would shape the trajectory of British scientific institutional life across the following four decades.

The configuration Banks bequeathed was operationally formidable and structurally vulnerable. It was formidable in what it had produced. The Royal Society at the center, with approximately seven hundred Fellows by 1820 and a continuing publication apparatus through *Philosophical Transactions*. The dissenting academies continuing as the principal alternative educational infrastructure, with the Manchester Academy and New College at Hackney as the operational inheritors of Warrington's tradition. The provincial societies operating at Manchester, Newcastle, Bristol, Derby, Liverpool, Leeds, and a growing number of additional regional centers. The Linnean Society at the disciplinary level for botany and zoology (founded 1788). The Geological Society at the disciplinary level for geology (founded 1807). The Royal Astronomical Society (founded 1820, just before Banks's death). Kew Gardens at the operational center of the global botanical work. The British Museum as the national collection. The patent system and the City of London's capital markets supplying the legal and financial infrastructure. The aggregate institutional density exceeded what any other European country had achieved.

It was vulnerable in its structural dependence on the configuration Banks had personally coordinated. The Royal Society's operational character under Banks's Presidency had been shaped by his particular pattern of personal management. The Society's Fellowship had expanded to include large numbers of aristocratic and gentry members whose interests in natural-philosophical work were limited to the social and ornamental dimensions of Fellowship — men whom Banks had cultivated for their political utility and whose election as Fellows had progressively diluted the active-scientific proportion of the Society's membership. The Society's institutional procedures had developed under Banks's personal direction in ways that did not depend on formal administrative structure; the personal direction would not be reproducible by his successors. The broader configuration Banks had coordinated through his Soho Square correspondence was, by 1820, a configuration whose operational coherence depended on the continuing presence of a coordinating

figure who could no longer be supplied because no other figure possessed the specific combination of personal wealth, royal favor, scientific standing, and personal energy that Banks had brought to the work.

The transition that followed produced an institutional reform whose specific features the rest of this Part will track. The reform did not proceed through a single coordinated effort. It proceeded through a series of separate institutional developments across the 1820s and 1830s — the Royal Institution's emergence into full operational character under Davy and then Faraday; the mechanics' institutes' multiplication beginning at Glasgow in 1823; the founding of University College London in 1826; the founding of the British Association for the Advancement of Science in 1831; the multiplication of specialist disciplinary societies across the same decade; the institutional reform of the Royal Society itself across the late 1820s and 1830s; the parliamentary university reforms of the 1850s. The aggregate of these separate developments produced, by the middle of the nineteenth century, a configuration that no longer depended on a single coordinating figure and that operated through institutional procedures whose specific features had been formalized in ways the Banks period had not required.

What the reform did not transform was the basic structural logic of the configuration. The Royal Society remained the central institution. The provincial and disciplinary societies operated as the regional and topical institutions. The educational system continued to expand. The capital markets continued to supply the financing. The patent system continued to supply the legal protection. The configuration the case has been tracking persisted through the reform, with modifications to its specific operational mechanisms but with continuity in its broader institutional pattern. What the reform produced was a configuration that could continue to operate at industrial scale without the specific coordinating figure that the Banks period had required.

II. The Royal Institution under Davy and Faraday

The institutional development that registered most operationally across the period from 1800 to approximately 1860 was the Royal Institution, founded in 1799 and operating from its premises at 21 Albemarle Street in Mayfair across the entire period. The Institution had been founded through the convergence of two figures whose relationship to the broader configuration was distinctive. Benjamin Thompson, Count Rumford — an American-born Loyalist who had moved to Bavaria after the Revolution, had reorganized the Bavarian army, had been made an Imperial Count in 1791, and had returned to London in 1798 — supplied the founding proposal and much of the early operational direction. Sir Thomas Bernard, a philanthropist associated with the Society for Bettering the Conditions and Improving the Comforts of the Poor, supplied much of the initial funding through that Society's subscriptions. Joseph Banks, in his capacity as Royal Society President, supplied the institutional connection that gave the new Institution its operational legitimacy within the broader configuration. The founding meeting was held on March 7, 1799, at Banks's house in Soho Square. The Institution was incorporated by Royal Charter in 1800. The Albemarle Street premises were purchased and adapted across the following months for the Institution's specific operational requirements — a large lecture hall with steep tiered seating designed for the public scientific demonstrations the Institution would conduct, a laboratory in the basement for the experimental work, a library on the upper floors.

The Institution's foundational principles, as articulated in Thompson's founding proposal, were specific. The Institution would conduct "the diffusion of the knowledge, and facilitating the general introduction of useful Mechanical Inventions and Improvements, and for teaching, by Courses of Philosophical Lectures and Experiments, the application of Science to the common Purposes of Life." The orientation was practical and public-facing. The Institution would supply, through its lectures and demonstrations, the public communication of scientific work that the Royal Society's more specialized institutional character did not adequately support. The lectures would be conducted at the highest level of contemporary scientific work and would be made available to the broader London educated public through subscription and ticket sales. The Institution's research laboratory would conduct work whose results would shortly appear in the lectures and in publications. The combination — high-level research conducted at a permanent London laboratory, communicated through public lectures to large audiences, supported by membership subscriptions — was a configuration the period had not previously produced.

The institutional development required the appointment of a capable lecturer-researcher. The first appointment, Thomas Garnett of the Andersonian Institute in Glasgow, did not succeed; his lectures were competently delivered but Thompson and Banks had concluded by 1801 that the Institution required a more dynamic figure. Humphry Davy was hired in February 1801 as Assistant Lecturer in Chemistry at a salary of £105 with accommodation. Davy was twenty-two years old. He had been working at Thomas Beddoes's Pneumatic Institute in Bristol on the medical applications of

gases (during which work he had identified nitrous oxide's anesthetic and intoxicating properties and had nearly killed himself through experimental inhalation). His scientific accomplishments to date were modest. His lecturing experience was minimal. What he brought to the Institution was a combination of genuine chemical capacity, exceptional public-speaking ability, and personal charisma whose operational consequences would profoundly shape the Institution's subsequent development.

Davy's lectures at the Royal Institution across the period from 1801 to approximately 1812 produced the institutional pattern through which the Institution would operate for the following century. The lectures drew packed audiences from across the London educated public — the gentry, the aristocracy, the wealthier commercial classes, the literary and artistic communities. Coleridge attended Davy's lectures; Wordsworth corresponded with him; the literary culture of Romantic London found in Davy's demonstrations the integration of science with imagination that the period's broader cultural sensibility required. Albemarle Street acquired such heavy carriage traffic on lecture days that it became, in 1810, London's first one-way street. The Institution's lecture audiences typically numbered five hundred to a thousand, with the Institution's lecture hall packed to its capacity on the major occasions.

Davy's research output across the same period was operationally consequential. His isolation of sodium and potassium in 1807 through the electrolysis of fused alkalis demonstrated the existence of chemical elements that no previous chemical technique had been able to identify and supplied the foundation for the systematic identification of the alkali and alkaline-earth metals that he would shortly complete. His isolation of calcium, strontium, barium, and magnesium followed in 1808. His identification of boron in 1808 and his characterization of chlorine as an element rather than a compound in 1810 extended the contribution. His invention of the miner's safety lamp in 1815, in response to the catastrophic colliery explosions that the expanding coal industry had been producing, supplied a practical industrial technology whose adoption across the Northumberland and Durham coalfields saved many miners' lives across the subsequent half-century. Davy's combination of public lecturing and serious research, conducted at the same institution across the same years, established the Royal Institution as a research-and-public-communication facility whose specific operational pattern would shortly be reproduced at other institutions across Britain and beyond.

The institutional successor to Davy was Michael Faraday, whose career at the Royal Institution would shape the institution's character across the period from 1813 to 1867. Faraday's biographical particulars deserve registration because they supply, in operational detail, what the institutional configuration had been built to accomplish. He had been born in 1791 in Newington Butts, south of London, the son of a Sandemanian blacksmith. His formal education had ended at thirteen, when he had been apprenticed to a London bookbinder for seven years. The apprenticeship had supplied him with access to the books he was binding — the *Encyclopaedia Britannica*, Jane Marcet's

Conversations on Chemistry, the broader range of natural-philosophical texts the bookseller handled — through which he had educated himself in chemistry and the broader natural-philosophical disciplines. In 1812 he had been given tickets by a customer to attend Davy's lectures at the Royal Institution. Faraday had taken extensive notes on the lectures, had bound the notes into a three-hundred-page manuscript volume, and had sent the volume to Davy in December 1812 with a letter requesting employment. Davy had been impressed by the manuscript and the letter. He had appointed Faraday as his chemical assistant at the Royal Institution in March 1813. The appointment was the operational mechanism through which the bookbinder's apprentice became, across the following half-century, one of the major figures of nineteenth-century natural philosophy.

Faraday's career at the Royal Institution can be specified at the level of institutional contribution. He succeeded Davy as Director of the Laboratory in 1825 after Davy's elevation to the Royal Society Presidency in 1820 and his subsequent decline through ill-health. He held the Fullerian Professorship of Chemistry at the Institution from 1833. He conducted, across his five decades at Albemarle Street, the experimental work whose results would shortly supply the foundations of nineteenth-century electrical and electromagnetic science. The discovery of electromagnetic induction in October 1831 — the demonstration that a changing magnetic field induces an electric current in a nearby conductor — was the operational foundation of the electrical generator, the electric motor, and the broader range of electrical technology that would shortly transform the industrial economy. The systematic experimental investigation of electromagnetic relationships across the following two decades produced what is now called Faraday's Law of induction (1831), the laws of electrolysis (1834), the experimental demonstration of the rotation of polarized light by a magnetic field (the Faraday effect, 1845), the conception of fields of force that would shortly be elaborated mathematically by James Clerk Maxwell into the equations of classical electromagnetism (Maxwell's *Treatise on Electricity and Magnetism* of 1873 would supply the mathematical formalization of what Faraday's experiments had established empirically).

The institutional structure within which Faraday conducted this work was the Royal Institution. The laboratory at Albemarle Street, the experimental apparatus the Institution maintained, the technical assistants the Institution employed, the time the Institution's salary supplied for him to work — these were the institutional resources without which the work would not have been conducted. Faraday's personal qualities supplied the experimental capacity that produced the specific results; the Institution's resources supplied the operational conditions within which the capacity could be exercised. The institution had been built to serve as a research-and-public-communication facility; in Faraday's hands it operated, across his half-century tenure, as the most productive single research laboratory in nineteenth-century natural philosophy.

The public-communication dimension continued in parallel with the research. Faraday founded the Royal Institution Christmas Lectures in 1825, an annual series of lectures aimed at young audiences during the Christmas holidays. He founded the Friday Evening Discourses in the same

year, a weekly hour-long lecture by an invited speaker on a topic of current scientific work. The Christmas Lectures continue at the Royal Institution to the present moment, broadcast on television since 1966 as one of the longest-running scientific public-communication programs in the world. The Friday Evening Discourses continue monthly. The pattern Faraday established — high-level scientific research conducted at the institutional center, public communication conducted through systematic lecture programs — was an institutional pattern that the broader configuration would shortly elaborate at other locations across Britain.

The Royal Institution by 1850 was, in operational terms, the principal research-and-public-communication facility of British natural philosophy. The Royal Society at Burlington House (after 1857) and Somerset House (before 1857) remained the central learned society. The British Association for the Advancement of Science remained the principal national meeting organization (Section IV will treat this). The provincial societies operated regionally. The specialist disciplinary societies operated at the topical level. The Royal Institution operated as the metropolitan research laboratory and public-communication center, supplying the institutional space within which the systematic experimental investigation of electromagnetic and chemical phenomena was being conducted at the level of detail and continuity that the broader configuration required.

III. The Mechanics' Institutes

The institutional development that registered most operationally at the level of the broader workforce was the mechanics' institutes movement, which began at Glasgow in 1823 and multiplied across Britain across the following two decades into a network of several hundred local institutions whose memberships ran into the hundreds of thousands.

The Glasgow Mechanics' Institute was founded in November 1823 by George Birkbeck. Birkbeck had been Professor of Natural Philosophy at the Andersonian Institute in Glasgow from 1799 to 1804 — the position from which Rumford had poached Thomas Garnett for the Royal Institution. During his Andersonian tenure Birkbeck had begun, in addition to his university lectures, a separate course of free scientific lectures specifically for working men of Glasgow whose occupational positions did not permit them to attend university but whose technical work required the basic scientific knowledge that the courses supplied. The working-class lectures had drawn audiences of approximately five hundred across the period of his Glasgow residence. Birkbeck had moved to London in 1804 to practice medicine; his medical practice had produced personal wealth that supplied the financial foundation for his subsequent institutional work.

The Glasgow Mechanics' Class continued under Birkbeck's successors after his departure. By 1823, when a dispute over institutional governance produced the separation of the working-class course from the Andersonian Institute's broader operations, Birkbeck supplied the institutional

vision for the new independent body. The Glasgow Mechanics' Institute opened in November 1823 with approximately five hundred members, conducting evening lectures and classes specifically for working men whose technical occupations required scientific instruction the existing educational institutions did not supply. Birkbeck reproduced the model at London in December 1823 with the founding of the London Mechanics' Institution, which would shortly be renamed Birkbeck College and would eventually become a constituent college of the University of London. The London Institution opened with approximately one thousand five hundred members within its first year.

The institutional pattern reproduced rapidly across Britain. By 1825 there were approximately twenty-five mechanics' institutes in operation across the country. By 1830 the figure had reached approximately one hundred. By 1850 it had reached approximately seven hundred institutes with combined memberships exceeding one hundred thousand. The institutes operated in nearly every English provincial town of any size, in the major Scottish industrial centers, in Wales, and in Ireland. The pattern was generalizable. Local committees of manufacturers, professionals, and skilled workers organized the institutes, raised the subscription funding required for their operations, hired lecturers for the evening classes, and built up the libraries, lecture rooms, and reading rooms that supplied the working population with scientific and technical education.

The pedagogical content was specific. The institutes' evening courses ran across natural philosophy (the contemporary term for physics), chemistry, mechanics, mathematics, drawing, and the broader range of technical subjects that the industrial economy required of its skilled workforce. The lectures were conducted at a level intended for working men whose formal education had typically ended at twelve or thirteen but whose occupational positions required scientific and technical knowledge that the elementary education system did not supply. The institutes maintained subscription libraries of approximately two to three thousand volumes typically, with sizeable holdings of scientific and technical texts alongside the broader literature of self-improvement that the period was producing. The institutes' reading rooms supplied the periodical literature — the *Mechanics' Magazine* from 1823, the *Penny Magazine* from 1832, the broader range of inexpensive periodical publications that the new mass-market printing technologies had made operationally feasible. The institutes' membership subscriptions were typically a few shillings per quarter, low enough to be within reach of the better-paid working population, high enough to supply the operational funding the institutes required.

What the mechanics' institutes accomplished, in operational terms, was the extension of the institutional configuration this case has been tracking downward to the skilled-worker level of the industrial economy. The Royal Society had supplied the apex institution. The dissenting academies and the universities had supplied the educated middle-class formation. The provincial societies had supplied the regional integration with industrial practice at the level of manufacturers and professionals. The mechanics' institutes supplied the educational infrastructure at the level of the skilled workers whose labor the industrial economy depended on. The configuration now operated,

by approximately 1840, at every level of the broader workforce — from the Royal Society's Fellows at the apex to the mechanics' institute members at the base, with all the institutional layers in between. The configuration was, in this respect, more complete than the configuration of any other European country. The institutional ecology supplied scientific and technical education at every level of the workforce that the industrial economy required. The supply was not always of high quality — the mechanics' institutes' actual pedagogical effectiveness was uneven, and many of them shortly became more recreational than educational in their operational character — but the institutional infrastructure existed. It existed in a form that could be improved as the demands of the broader configuration required improvement.

IV. The British Association for the Advancement of Science

The institutional reform that registered most operationally at the level of the broader scientific community was the founding of the British Association for the Advancement of Science in 1831. The Association's specific founding circumstances and operational character deserve registration because the Association would shortly become, alongside the Royal Society, the principal coordinating institution of the broader configuration across the following century.

The Association emerged from a particular institutional dispute that had been developing within the Royal Society across the 1820s. Charles Babbage, who had been a Fellow of the Royal Society since 1816 and had become, across the 1820s, one of the most vocal critics of the Royal Society's contemporary operational character, published in 1830 a vigorous polemic titled *Reflections on the Decline of Science in England and on Some of its Causes*. The argument was specific. The Royal Society, in Babbage's reading, had become an institutionally captured body whose Fellowship was largely composed of aristocratic and gentry members with limited interest in active scientific work, whose Presidency was conducted by figures (Davies Gilbert had succeeded Banks in 1820 and held the Presidency through 1827; the Duke of Sussex was elected in 1830) whose scientific qualifications were modest, whose Council operations were dominated by social and political considerations rather than scientific merit, and whose institutional pattern had drifted significantly from the operational scientific commitment the Society had been founded to maintain. The polemic was long, sharp in tone, and provocative in its political and personal implications. It produced, across the British scientific community, an immediate response.

The response divided the community. Some, including Faraday at the Royal Institution, considered Babbage's critique unfair and personally motivated; Faraday arranged for Gerrit Moll of Utrecht to write a published response titled *On the Alleged Decline of Science in England* (1831). Others, including David Brewster of Edinburgh, James Forbes also of Edinburgh, John Herschel, Roderick Murchison, and the broader Scottish and provincial scientific communities, considered the critique largely accurate and acted on its implications. The acting was conducted principally by William Vernon Harcourt, an Anglican clergyman based in York whose interest in science had

developed through the Yorkshire Philosophical Society of which he was a leading figure. Harcourt, with the support of Brewster and the others, organized a meeting at York in September 1831 to establish a new national scientific organization whose institutional structure would address what they considered the Royal Society's structural inadequacies.

The first meeting of what became the British Association for the Advancement of Science was held at the Yorkshire Museum at York on Tuesday September 27, 1831. Approximately three hundred persons attended. Viscount Milton, the President of the Yorkshire Philosophical Society, chaired the meeting. Various scientific papers were presented across the following days. The Association adopted a constitution that supplied the operational structure for its subsequent work. The constitution specified that the Association would meet annually in different provincial centers across Britain, with the meeting location rotating among the major regional cities to supply national representation; that the meetings would be organized into specialist sections (initially Mathematics and Physics, Chemistry, Geology, Natural History, Statistics, Mechanical Arts) within which the working scientific community could conduct its specialized discussions; that the meetings would produce published proceedings supplying the broader community with the scientific work conducted at the sessions; and that the Association's membership would be open on subscription to anyone with serious scientific interests rather than restricted by the Royal Society's election procedures.

The institutional model was specifically borrowed from the Gesellschaft Deutscher Naturforscher und Ärzte — the German Association of Naturalists and Physicians — which had been operating in the German states since 1822 on the rotating-annual-meeting model. The German Association had been admired by the British scientific community across the 1820s as an operational example of the kind of national scientific organization that British conditions had not yet produced. The British Association reproduced the model in British conditions and would shortly produce, across the period from 1831 forward, a continuing series of annual meetings whose operational pattern would supply the national coordinating mechanism the British scientific community had previously lacked.

The Association's institutional contributions across its early decades were operationally consequential. The annual meetings, held at York (1831), Oxford (1832), Cambridge (1833), Edinburgh (1834), Dublin (1835), Bristol (1836), Liverpool (1837), and subsequent provincial centers, supplied the institutional locus at which the working scientific community across Britain assembled annually for the demonstration of new work, the discussion of contested questions, and the development of the personal connections that the broader configuration required. The Association's Reports, published annually from 1832 onward, supplied the operational record of the meetings and reached an audience much broader than *Philosophical Transactions* had reached. The Association's specialist sections supplied the disciplinary specialization that the period's increasingly specialized scientific work required and that the Royal Society's broader generalist

structure did not adequately accommodate. The Association's national membership — open on subscription, not requiring Fellowship election — supplied an institutional channel that the provincial scientific community could access at a scale the Royal Society's metropolitan structure had not permitted.

The Association's relationship with the Royal Society was contested across the early 1830s. The Royal Society Council initially regarded the Association with suspicion — as a rival institution whose founding challenged the Royal Society's traditional position as the central institution of British science. The relationship stabilized across the subsequent decade as the operational distinction between the two institutions emerged: the Royal Society as the metropolitan central institution, with Fellowship as a recognition of distinguished scientific accomplishment; the British Association as the national meeting organization, with membership open to the broader scientific community. The two institutions operated, after the initial period of tension, as complementary rather than rival components of the broader configuration.

What the Association's founding accomplished, at the structural level the case has been tracking, was the institutional reform that distributed the central coordinating function that Banks had previously supplied through his personal labor. The Association's annual meetings supplied a coordinating function that no individual could supply. The Association's sections supplied the disciplinary specialization that the increasingly specialized scientific work required. The Association's national membership supplied the broader institutional reach that the Royal Society's metropolitan structure had not provided. The configuration the case has been tracking now operated, by approximately 1840, through institutional mechanisms whose continuity did not depend on any single person's personal labor and whose operational reach extended across the full national scientific community.

V. The Specialist Societies and the University Reforms

Two additional institutional developments across the period from 1820 to 1860 deserve specification because the configuration the case is tracking required both for its operational completion.

The first was the multiplication of specialist disciplinary societies across the same period. The Linnean Society had been founded in 1788 under Banks's patronage for botany and zoology. The Geological Society had been founded in 1807 by William Maton, James Parkinson, and others for the specialist study of geological questions whose disciplinary specificity the Royal Society's broader structure did not adequately accommodate. The Royal Astronomical Society followed in 1820, founded by Babbage, Herschel, and others. The Statistical Society of London followed in 1834, again with Babbage as one of its founders. The Chemical Society of London followed in 1841. The Royal Microscopical Society in 1839. The Royal Entomological Society in 1833. The

Royal Meteorological Society in 1850. The Royal Anthropological Institute, through various predecessor organizations, across the 1860s and 1870s. The pattern was specific. As each scientific discipline developed sufficient specialist content to require disciplinary institutional infrastructure of its own, the specialist community organized to establish that infrastructure through a separate learned society. The aggregate by 1860 was a configuration of disciplinary societies operating in parallel with the Royal Society at the apex, the British Association at the national meeting level, and the provincial societies at the regional level.

The institutional logic that drove the multiplication deserves registration. Each specialist society had been founded by figures whose specific disciplinary work required infrastructure the broader institutions did not adequately supply. The Geological Society's founders required specialist meetings and publications devoted exclusively to geological questions, which the Royal Society's broader agenda could not accommodate at the depth the work required. The Astronomical Society's founders required specialist meetings on astronomical questions for the same reason. The pattern reproduced as each discipline developed sufficient specialized content. The configuration the case has been tracking now operated, by 1860, with institutional infrastructure at the disciplinary level alongside the broader institutional layers. The specialist societies were not separate from the broader configuration; they were institutional specializations within it, with overlapping memberships, shared participants, and integrated publication channels that connected the specialist work to the broader scientific community.

The second was the reform of the English universities, which had operated through the eighteenth century with a curricular conservatism that this case has previously registered as part of the structural feature that produced the dissenting academies. The reform proceeded across the period from approximately 1820 to 1860 through a combination of new institutional foundings and parliamentary reform of the existing universities. University College London was founded in 1826 as the first English university to admit students without religious test, supplying the institutional infrastructure for higher education to the dissenting and the broader non-Anglican populations that the older universities had excluded. The institution was non-denominational by design and provided instruction across the modern subjects (modern languages, history, political economy, the natural sciences) that the older universities had not adequately accommodated. King's College London followed in 1829 as the Anglican response, founded specifically to supply higher education to Anglican students who would not attend the non-denominational University College. The University of London was chartered in 1836 to provide the degree-granting authority that the two London colleges required, with the broader London medical schools shortly incorporating into the federal structure.

The Test Act and Corporation Act repeal of 1828 had removed the legal disability that had excluded the dissenters from the older institutions, though Oxford and Cambridge retained their religious tests for matriculation and degrees through the 1850s. The University Tests Act of 1854 at

Oxford and 1856 at Cambridge formally opened the older universities to non-Anglican students; the Universities Tests Act of 1871 finally removed the religious tests for fellowships and academic positions at the older universities, completing the legal opening that had begun with the 1828 repeal. The parliamentary commissions of the 1850s at both Oxford and Cambridge produced the curricular reforms that brought the modern subjects — the natural sciences, modern languages, modern history, political economy — into the established universities' curricula. Cambridge added a Natural Sciences Tripos in 1851; Oxford established its Honour School of Natural Science in the same year. The reforms transformed the older universities, across the second half of the nineteenth century, into institutions whose curricular content and intellectual character bore much less resemblance to the eighteenth-century institutions than to the configuration the dissenting academies had pioneered.

The new universities of the industrial provinces followed across the 1850s and 1860s. Owens College at Manchester opened in 1851, supplying higher education to the Manchester region. Birmingham's Mason Science College opened in 1875. The Yorkshire College at Leeds opened in 1874. The University College of South Wales and Monmouthshire at Cardiff opened in 1883. These institutions, which would shortly become the constituent colleges of the federal Victoria University and eventually the independent University of Manchester, the University of Birmingham, the University of Leeds, and the University of Wales, supplied the regional university infrastructure that the industrial economy of the second half of the nineteenth century required. The institutional pattern the dissenting academies had pioneered — practical curriculum, regional location, integration with local industrial work — was reproduced at university scale across the industrial provinces. The configuration the case has been tracking now operated, by approximately 1880, through a network of universities at metropolitan and provincial scale whose curricular and institutional pattern bore the structural inheritance of what the dissenting academies had developed across the eighteenth century.

VI. The Configuration at Full Operational Scale

By approximately 1850 the configuration the case has been tracking had reached what can reasonably be described as its full operational scale. The institutional components can be enumerated.

The Royal Society at Somerset House (and from 1857 at Burlington House) continued as the central learned society, with approximately seven hundred Fellows by 1850. *Philosophical Transactions* continued in regular publication. The Society had begun, across the 1840s, the institutional reforms that would shortly distinguish active scientific Fellows from the broader honorary membership and that would shortly reduce the aristocratic and gentry composition that the Banks period had encouraged. The Society's relationship with the broader configuration was institutionally consolidated.

The British Association for the Advancement of Science conducted annual meetings in different provincial centers. By 1850 the Association had held annual meetings at York (1831), Oxford (1832), Cambridge (1833), Edinburgh (1834), Dublin (1835), Bristol (1836), Liverpool (1837), Newcastle (1838), Birmingham (1839), Glasgow (1840), Plymouth (1841), Manchester (1842), Cork (1843), York again (1844), Cambridge again (1845), Southampton (1846), Oxford again (1847), Swansea (1848), Birmingham again (1849), and Edinburgh again (1850). The rotating-meeting pattern had supplied the national coordinating function that the configuration required. The Association's published Reports supplied the broader communication of the work conducted at the meetings.

The specialist disciplinary societies — Linnean, Geological, Astronomical, Statistical, Chemical, Microscopical, Entomological, the others — operated at the disciplinary level, conducting specialist meetings and publishing specialist proceedings. The aggregate by 1850 was a network of approximately twenty London-based specialist learned societies operating in parallel with the Royal Society at the apex.

The provincial scientific societies — Manchester Lit and Phil, Newcastle Lit and Phil, Birmingham (the post-Lunar Birmingham Philosophical Society), Bristol, Derby, Liverpool, Leeds, Sheffield, Hull, and approximately twenty additional regional centers — operated at the regional level. Their combined memberships ran into the thousands. Their published proceedings supplied the regional record of scientific and industrial work conducted across the provinces.

The Royal Institution at Albemarle Street operated as the principal metropolitan research-and-public-communication facility, with Faraday conducting the experimental work that produced the foundations of electromagnetic theory and the Friday Evening Discourses and Christmas Lectures supplying the public communication. The Institution's specific operational pattern had been reproduced in various forms at the Liverpool Royal Institution (1814), the Manchester Royal Institution (1823), the Bristol Philosophical Institution (1819), and the broader range of provincial institutions whose names registered the Royal Institution's structural example.

The mechanics' institutes operated at the working-class educational level, with approximately seven hundred institutes across Britain and combined memberships exceeding one hundred thousand. The institutes supplied the technical education infrastructure that the broader industrial workforce required.

The universities — Oxford, Cambridge, University College London, King's College London, the new provincial universities beginning to be founded — operated at the higher educational level, with their curricular character increasingly accommodating the modern scientific subjects that the dissenting academies had pioneered.

The patent system, reformed by the Patent Law Amendment Act of 1852 that reduced the bureaucratic cumbersomeness of the older system and made patents accessible to a broader range of

inventors, supplied the legal protection for inventions.

The capital markets of the City of London supplied the financial infrastructure for the commercial development of new technologies at a scale that had grown enormously across the railway boom of the 1840s.

The aggregate institutional configuration was the densest national scientific infrastructure in the world. No other country approached it. France retained its centralized state-academic structure and produced excellent specialist work but had not developed the integrated provincial-and-disciplinary network that British institutional development had produced. The German states were beginning, across the same period, the university reforms (Berlin had been founded in 1810 under Humboldt's influence; Giessen had developed Justus von Liebig's chemistry program from 1825) that would shortly transform German higher education into the leading research-university system in the world, but the German configuration in 1850 had not yet completed the transformation. The United States was beginning, in the same period, the construction of the higher-education infrastructure that this case's companion case *The Believer's Republic* has traced, but had not yet developed the institutional density that British science possessed. The British configuration was, at the middle of the nineteenth century, the world's principal scientific institutional infrastructure.

VII. The Naturalist on the Beagle

The configuration produced, across the period from 1825 to 1859, what may have been its most operationally consequential single intellectual output. Charles Robert Darwin had been born in February 1809 at Shrewsbury, the second son of Robert Waring Darwin, a successful physician, and Susannah Wedgwood, the daughter of Josiah Wedgwood of the Lunar Society. The familial connections registered the structural feature this case has been tracking. Darwin's two grandfathers — Erasmus Darwin and Josiah Wedgwood — had been central figures of the Lunar Society of Birmingham across the late eighteenth century. Darwin's mother had grown up in the Wedgwood household at Etruria where Priestley and the broader Lunar circle had been frequent visitors. The Wedgwood family fortune, accumulated through Josiah Wedgwood's industrial work and managed across the subsequent two generations, supplied the financial security that would shortly permit Darwin to devote his working life to natural-historical research without requiring institutional employment for income. The Lunar Society's institutional and intellectual inheritance ran, in Darwin's case, directly through to the natural-historical work he would conduct across his subsequent career.

Darwin's formal education was institutional in ways that registered the configuration's full structure. He had attended Shrewsbury School, the local grammar school, where his classical education had been competent but uninspiring. He had enrolled at Edinburgh University in 1825 to study medicine — Edinburgh having retained its position as one of the principal British medical

training centers, with strong dissenting and scientific connections that the Anglican universities had not matched. His Edinburgh studies had introduced him to Robert Grant, the naturalist whose Lamarckian evolutionary commitments had shaped Darwin's early exposure to evolutionary thinking. Darwin had transferred to Cambridge in 1828 to prepare for the Anglican clergy after his medical training had failed to engage him; his Cambridge studies had introduced him to John Stevens Henslow, the Professor of Botany whose mentorship would shortly produce the operational connection through which Darwin's subsequent career was made.

The *Beagle* voyage came through Henslow's institutional connection. Robert FitzRoy, the captain of HMS *Beagle* preparing for a hydrographic surveying voyage to South America and the Pacific, had requested a naturalist-companion for the voyage. Henslow had recommended Darwin, who was twenty-two years old and had no formal scientific credentials beyond his Cambridge degree. The voyage departed Plymouth on December 27, 1831, and returned to Falmouth on October 2, 1836 — nearly five years of continuous travel during which Darwin conducted natural-historical observation and specimen collection across the coasts of South America, the Galápagos Islands, Tahiti, New Zealand, Australia, and the broader Pacific. The voyage was the operational mechanism through which Darwin's natural-historical work was begun. The specimens he collected and the observations he recorded supplied the empirical foundation for the subsequent twenty-three years of research that would produce *On the Origin of Species*.

Darwin's career after the *Beagle*'s return registered the configuration's institutional integration. He was elected to the Geological Society in 1836 immediately on his return, presented his first papers on the geology of South America to the Society across 1837 and 1838, and served as its Secretary from 1838 to 1841. He was elected to the Royal Society in 1839. He published the *Journal of Researches* (now generally known as the *Voyage of the Beagle*) in 1839 through John Murray. He published his geological work on the *Beagle* observations across the early 1840s — *The Structure and Distribution of Coral Reefs* (1842), *Geological Observations on the Volcanic Islands* (1844), *Geological Observations on South America* (1846). His monograph on the cirripedes (barnacles), conducted across the period from approximately 1846 to 1854, established his credentials as a working systematic biologist and produced four major published volumes. His private work on the theory of evolution through natural selection, which he had been conducting since approximately 1837 when he had first sketched the theoretical apparatus in his notebooks, accumulated across the same period without publication.

The institutional infrastructure within which Darwin conducted this work can be specified. He lived at Down House in Kent from 1842, retiring from London on income from his family inheritance and from his published books. He conducted correspondence with naturalists across the world — Joseph Dalton Hooker at Kew, Asa Gray at Harvard, Charles Lyell as his closest London scientific friend and intellectual mentor, the broader network of naturalists, botanists, geologists, and zoologists whose specialist work supplied the empirical content Darwin's evolutionary theory

required. He participated in the Royal Society and the Geological Society and the Linnean Society through correspondence and through occasional London visits. He drew on the Royal Botanic Gardens at Kew for botanical material. He drew on the British Museum's natural-history collections for specimens and comparisons. He drew on the published proceedings of the British Association meetings for current research. The institutional configuration the case has been tracking supplied, in operational terms, the specific resources Darwin's twenty-three years of evolutionary research required. The work was conducted in private at Down House, but the resources required for the work were the resources the broader configuration had built.

The publication of *On the Origin of Species* in November 1859 was the operational moment at which the configuration's most consequential single intellectual product reached its audience. The specific circumstances of the publication deserve registration. Darwin had been preparing a much longer book on the evolutionary theory across the late 1850s, working at the deliberate pace his Down House routine permitted. In June 1858 he received a letter from Alfred Russel Wallace, a younger naturalist conducting research in the Malay Archipelago, containing a short paper sketching what was, in its essential features, the same theory of evolution through natural selection that Darwin had been developing across two decades. Wallace's paper had been independently developed; the convergence was real. Darwin's response, conducted through correspondence with Lyell and Hooker, was the institutional resolution that produced the joint publication of Darwin's and Wallace's papers in the *Journal of the Proceedings of the Linnean Society* on August 20, 1858. The joint publication established the priority of both men on the theory while preserving Darwin's institutional position as the principal expositor of the work.

On the Origin of Species by Means of Natural Selection, abbreviated from Darwin's longer manuscript across the year following the Wallace letter, was published by John Murray on November 24, 1859. The print run was 1,250 copies. The volume sold out on the first day. Subsequent editions across the following decade reached much broader audiences in Britain and translation editions reached the major European languages. The work would supply, across the following century and a half, the operational foundation of evolutionary biology, the integrative framework within which natural-historical work in zoology, botany, paleontology, and the emerging genetic and molecular sciences would be conducted, and one of the most consequential single intellectual works in the entire history of the natural sciences.

What this Part needs to register about the *Origin*'s publication is the institutional dimension of what the configuration had supplied. The work would not have been possible without Darwin's specific intellectual capacity; that was the necessary condition. The work would not have been published in the form and at the time it was published without the institutional configuration the case has been tracking; that was the operational condition. The Geological Society's institutional acceptance of Darwin's geological work across the late 1830s and 1840s, the Royal Society's institutional acceptance of him as a Fellow from 1839, the Linnean Society's institutional

management of the Wallace priority through the joint publication of August 1858, John Murray's commercial publishing apparatus that brought the book to its readership, the broader correspondence network through which Darwin's empirical research had been conducted, the institutional connections that supplied Darwin with the family inheritance that financed his Down House routine — these were the operational mechanisms through which the work was conducted, communicated, and integrated into the broader configuration. Newton without the Royal Society. Watt without Boulton and the Lunar Society. Darwin without the institutional configuration the British scientific community had built across two centuries. The intellectual work in each case was the necessary condition. The institutional configuration was the operational condition.

The next Part will examine what the configuration accomplished by 1859 at the level of the broader civilizational comparison the case has been tracking, and what the configuration's specific institutional features had supplied that the comparable institutional configurations of other civilizations had not produced.

Part VI — The Configuration at Peak and the Comparative Resolution

I. The Configuration in 1859

The publication of *On the Origin of Species* on November 24, 1859, supplies a date at which the configuration this case has been tracking can be assessed at the peak of what it accomplished. The accomplishment was operationally formidable at every institutional layer the previous Parts have specified, and the assessment is worth registering at the level of operational detail before the comparative resolution that the rest of this Part will conduct.

The Royal Society at Burlington House — having moved from Somerset House in 1857 — operated with approximately seven hundred Fellows whose collective work constituted the central activity of British natural philosophy. *Philosophical Transactions* continued its weekly publication through the operational mechanisms the late seventeenth century had established and the subsequent two centuries had refined. The Society's institutional reforms across the 1830s and 1840s had progressively distinguished active scientific Fellows from honorary members; the operational character of the institution was being restored to its founding commitment to natural-philosophical work after the broader social-membership pattern Banks had cultivated during his Presidency. The Society's relationship with the broader configuration was institutionally consolidated. It operated as the central learned society, with its specific structural position no longer contested by the British Association or the specialist societies that had emerged across the previous three decades.

The British Association for the Advancement of Science had completed its twenty-ninth annual meeting at Aberdeen in September 1859, two months before the *Origin* appeared. Approximately two thousand five hundred persons had attended the Aberdeen meeting. The Association's sections — by 1859, the structure included Mathematical and Physical Science, Chemistry, Geology, Biology, Geography and Ethnology, Statistical Science, Mechanical Science — supplied the disciplinary specialization that the increasingly specialized natural-philosophical work required. The Aberdeen Reports, published the following year, ran to several hundred pages and supplied the documentary record of the work conducted at the sessions. The Association's national reach extended to every major provincial center in Britain. Its membership exceeded ten thousand by the late 1850s.

The Royal Institution at Albemarle Street, with Faraday in his final productive years as Fullerian Professor of Chemistry, supplied the principal metropolitan research-and-public-communication facility. The Friday Evening Discourses and Christmas

Lectures continued at their established cadence. The laboratory continued its experimental work. The lecture hall continued to draw audiences of several hundred for the major demonstrations.

The specialist societies — Linnean (1788), Geological (1807), Astronomical (1820), Statistical (1834), Chemical (1841), Microscopical (1839), Entomological (1833), Meteorological (1850), the other emerging disciplinary institutions — operated at the topical level with combined memberships of several thousand and combined publication output of approximately a dozen specialist periodicals. The aggregate disciplinary institutional infrastructure was the densest in Europe.

The provincial societies — Manchester, Newcastle, Birmingham, Bristol, Derby, Liverpool, Leeds, Sheffield, Hull, the broader network of approximately fifty regional learned societies — operated at the regional level with combined memberships in the tens of thousands. The provincial publication output supplied the regional documentary record of natural-philosophical and industrial work conducted across the British provinces.

The mechanics' institutes — approximately seven hundred operational institutes across Britain by 1859 — supplied the technical educational infrastructure at the working-class level. Combined memberships exceeded one hundred thousand. The institutes' libraries contained, in aggregate, approximately one and a half million volumes accessible to the broader working population.

The universities — Oxford and Cambridge with their newly reformed Tripos and Honour School structures, University College London and King's College London at the metropolitan level, Owens College Manchester from 1851 as the first of the new provincial institutions — supplied the higher educational infrastructure whose curricular content increasingly accommodated the modern natural-philosophical and applied subjects.

The patent system, reformed by the Patent Law Amendment Act of 1852, supplied the legal protection for inventions at a much lower cost than the older system had permitted.

The capital markets of the City of London supplied the financial infrastructure for industrial enterprise at the largest scale in Europe.

The aggregate institutional configuration in 1859 was the densest scientific institutional infrastructure in the world. The configuration operated at every level of the broader workforce — from the Royal Society's Fellows at the apex to the mechanics' institute members at the base, with the universities, the specialist societies, the provincial societies, the Royal Institution, and the British Association supplying the intermediate institutional layers. The configuration had been built across two hundred thirty years from Bacon's *New Atlantis* of 1627 forward, through the institutional decisions of successive generations of natural philosophers, industrialists, educators, and the broader cohort of figures whose work the previous Parts have traced. The aggregate that the configuration produced, taken in operational terms across the broader civilizational measure, supplied the foundation of the world's first industrial economy and the world's first sustained

tradition of cumulative scientific work at industrial scale.

The question this Part will now address is what the configuration produced that the institutional configurations of other civilizations had not produced. The civilizations against which the comparison can usefully be drawn are specifiable. China during the same period was operating under the imperial examination system that the Sui and Tang dynasties had institutionalized and the Song through Qing dynasties had elaborated into the most operationally consequential meritocratic talent-recruitment system the premodern world produced. The Abbasid period in the Islamic world had produced, across the ninth through eleventh centuries, an extraordinary scientific output that subsequent institutional developments had not sustained. Medieval and early modern Catholic Europe had constrained natural-philosophical work in specific ways whose operational consequences for the work this case has tracked deserve registration. France had developed, across the seventeenth and eighteenth centuries, the state-centric Académie des Sciences whose specific operational features had differed from the English configuration in ways the case has previously noted. The German states had begun, across the early nineteenth century, the university reforms that would shortly produce the dominant research-university system in the world but had not yet completed that transformation by 1859. The Netherlands had produced extraordinary scientific work in the seventeenth century without developing the broader institutional infrastructure required to sustain it across subsequent generations.

The comparison the rest of this Part will conduct is not about which civilization produced the most brilliant individual minds. The comparison is about which institutional configuration was best suited to the cumulative preservation, transmission, and elaboration of natural-philosophical work across successive generations. The English configuration's specific features had supplied, by 1859, what the comparable institutional configurations of other civilizations had not supplied. The point of the comparison is structural rather than competitive. The English achievement was institutional rather than racial or cultural in any essentialist sense. The institutional configuration could in principle have emerged elsewhere; the historical contingencies of where and when it did emerge are the contingencies the case has tracked.

II. China and the Examination System

The most consequential alternative institutional configuration the premodern world produced was the Chinese imperial examination system — the *keju* — that the Sui dynasty had systematized in the late sixth century, that the Tang dynasty had developed across the seventh and eighth centuries, that the Song dynasty had refined into its mature form across the tenth and eleventh centuries, and that the Ming and Qing dynasties had operated, with periodic modifications, until the system's abolition in 1905 under the late Qing modernization. The system operated continuously for approximately thirteen centuries — a duration far exceeding the institutional life of any specific Western institution the case has tracked. The system's specific operational features deserve registration because the comparison with the English configuration depends on what those features were and were not.

The examination system was, in its operational character, a meritocratic talent-recruitment apparatus through which the imperial government selected the men who would staff its bureaucratic administration. The examinations operated at four institutional levels — district, provincial, metropolitan, and palace — with successful candidates at each level qualifying for the next. The district examinations were administered annually or every two years. The provincial examinations every three years. The metropolitan examinations every three years following the provincial successes. The palace examinations, conducted in the presence of the emperor at the imperial capital, supplied the final ranking among the metropolitan successes. The top-ranked metropolitan-and-palace candidates — designated *jinshi* — received the most senior bureaucratic appointments. Lower-ranked candidates received correspondingly lower appointments. The aggregate of successful candidates across the system's operational life supplied the men who occupied the bureaucratic positions through which imperial China was governed.

The institutional consequences were operationally significant in ways that deserve specification. The examination content, after the system's mature consolidation in the Song dynasty, was largely confined to the Confucian classics — the *Four Books* (the *Analects* of Confucius, the *Mencius*, the *Great Learning*, the *Doctrine of the Mean*) and the *Five Classics* (the *Book of Changes*, the *Book of Documents*, the *Book of Songs*, the *Book of Rites*, the *Spring and Autumn Annals*) — supplemented in various periods by the *Five Studies* (military strategy, civil law, revenue and taxation, agriculture, and geography). The candidates spent their formative intellectual years memorizing the classical texts, studying the accepted commentaries, and learning to compose essays in the prescribed form (the so-called eight-legged essay of the Ming and Qing periods). The system absorbed, generation after generation, the most talented young men of Chinese society into a curriculum whose specific content was the literary and ethical inheritance of the classical tradition rather than the systematic investigation of the natural world.

What the system did not do was develop institutional infrastructure for the cumulative preservation and transmission of natural-philosophical work at the scale and continuity that the English configuration produced. China had produced, across its long civilizational history, an extraordinary body of natural-philosophical and technological work. Joseph Needham's *Science and Civilisation in China* documented, across its multi-volume compilation, the Chinese inventions and discoveries that had preceded their European counterparts by centuries — paper-making (Han dynasty, second century), the magnetic compass (Han dynasty, first century), gunpowder (Tang dynasty, ninth century), movable-type printing (Song dynasty, eleventh century), the seismograph (Han dynasty, second century), the iron plow, the wheelbarrow, the suspension bridge, the broader range of technical innovations whose Chinese origins the European subsequent adopters had not always recognized. The Song dynasty in particular had produced, across the eleventh and twelfth centuries, scientific and technological accomplishments that placed China far ahead of contemporary Europe. Shen Kuo's *Dream Pool Essays* of approximately 1088 supplied a compendium of natural-philosophical observations whose range and quality matched or exceeded what contemporary European authors were producing. The Chinese scientific moment of the Song period was real.

What the Chinese institutional configuration did not produce was the apparatus for the continuing development of the work that the Song moment had achieved. The examination system, in its mature operational character, oriented the talent of successive generations toward the classical curriculum rather than toward the further investigation of the natural world. The civil-service appointments that successful candidates received were administrative positions whose operational responsibilities ran across the broad range of imperial governance — provincial administration, judicial work, taxation, military supervision, ritual and ceremonial functions — but not specifically toward natural-philosophical research. The bureaucratic positions did not include the kind of institutional support for continuing natural-philosophical work that the Royal Society Fellows possessed through the institutional framework of the Society itself. The Chinese scientific work that had been conducted in the Song period was, in many specific cases, preserved through the documentary tradition of the imperial archives and the literati's private libraries, but it was not extended through the kind of continuing institutional apparatus that the European configuration had built.

The historian Joseph Needham, who devoted his working life to the documentation of Chinese science and to the question of why the Industrial Revolution had emerged in Europe rather than in China, formulated what would become known as the Needham Question. China, Needham observed, had been considerably more advanced than Europe across the period from approximately the third century through the fifteenth century in most measures of scientific and technological accomplishment. Why then, Needham asked, had the cumulative natural-philosophical work that produced what we now call modern science emerged in Europe rather than in China across the period from approximately 1500 to 1800? Various answers have been proposed across the

subsequent decades of historiographical debate — geographic, political, economic, religious, climatic. The answer the present case suggests, without claiming to settle the broader question, is that the answer is institutional. China did not develop, across the relevant historical period, the institutional configuration that the case has been tracking. The Chinese institutional configuration was operationally formidable — the imperial bureaucracy, the examination system, the literati tradition, the imperial academies and libraries — but its specific features were not oriented toward what the English configuration was oriented toward.

The Chinese institutional configuration was oriented toward the reproduction of imperial governance through the classical curriculum and the bureaucratic apparatus. The English configuration was oriented toward the cumulative preservation, transmission, and extension of natural-philosophical work through the institutional mechanisms the case has traced. The orientation difference was structural. The Chinese system absorbed the talent of successive generations into the classical curriculum and the bureaucratic positions. The English system, particularly after the institutional developments of the seventeenth and eighteenth centuries, channeled comparable talent into natural-philosophical work, technical innovation, and the broader cultural prestige of scientific accomplishment that the English configuration had built. Neither orientation was inherently superior. The orientations had specific consequences. The Chinese orientation produced one of the longest-running and most operationally formidable bureaucratic civilizations in human history. The English orientation produced the world's first industrial economy and the world's first sustained tradition of cumulative natural-philosophical work at industrial scale. The orientations had been built across different historical periods, in response to different specific conditions, and produced different specific outcomes.

The specific point this case requires is that the Chinese configuration's absence of the institutional features the English configuration possessed was the operationally consequential difference. China had natural-philosophical capacity in abundance. The capacity was institutionally captured by the examination system and the bureaucratic apparatus rather than by an institutional configuration oriented toward the cumulative development of natural-philosophical work itself. The intellectual capacity went where the institutional configuration directed it. In China the institutional configuration directed it toward the classical curriculum and the bureaucratic positions. In England the institutional configuration directed it toward natural-philosophical work and the broader scientific-technical apparatus the case has traced. The institutional memory the case has been tracking included, in the Chinese case, the memory of the classical curriculum and the bureaucratic tradition. In the English case, the institutional memory included what the case has been tracking — the cumulative preservation and extension of natural-philosophical work across the institutional channels the Royal Society and the broader configuration had built.

III. The Abbasid Period and Its Institutional Aftermath

The second civilizational comparison the case requires is the Abbasid period in the Islamic world — the period from approximately the eighth through the eleventh centuries during which the Islamic civilization produced what subsequent observers have called the Islamic Golden Age of science and philosophy. The Golden Age was operationally formidable. The translation movement of the eighth and ninth centuries, conducted under the patronage of the Abbasid caliphs at Baghdad and supported by the establishment of the House of Wisdom (Bayt al-Hikma) under Caliph al-Ma'mun (reigned 813-833), produced Arabic translations of the major Greek philosophical and scientific texts — Aristotle, Plato, Ptolemy, Galen, Euclid, Archimedes, the broader corpus of classical natural-philosophical work that the Hellenistic and Roman periods had preserved. The subsequent Islamic scientific work, conducted across the ninth through eleventh centuries by figures whose accomplishments deserve specification, supplied much of what would shortly be transmitted to medieval Europe and would become the foundation of the European scientific recovery of the high Middle Ages and the early modern period.

The figures and their accomplishments can be enumerated briefly. Al-Khwarizmi (approximately 780-850) at Baghdad conducted the algebraic work whose Latinized name (algorithmus) and Arabic-derived terms (algebra from *al-jabr*) supply the etymological evidence of the subsequent European inheritance. Al-Razi (Rhazes, 854-925) conducted medical and chemical work whose published treatises supplied much of the European medical curriculum through the fifteenth century. Al-Biruni (973-1048) conducted astronomical, mathematical, geographical, and historical work whose comprehensive scope had no contemporary European equivalent. Ibn al-Haytham (Alhazen, 965-1040) conducted the optical work that produced the *Book of Optics* whose subsequent European reception supplied the foundation for medieval and Renaissance optical investigation through Roger Bacon and ultimately Kepler. Ibn Sina (Avicenna, 980-1037) conducted philosophical and medical work whose *Canon of Medicine* would shortly become the standard medical text in Europe and would remain so for approximately five centuries. The Islamic scientific moment was real and operationally consequential. The European scientific recovery of the high Middle Ages would not have been possible without it.

What the Islamic institutional configuration did not produce was the apparatus for the continuing development of the work that the Golden Age had achieved. The institutional development that emerged across the eleventh and twelfth centuries, in response to specific political and religious conditions of the period, redirected the institutional focus of the Islamic intellectual class away from natural-philosophical work and toward the systematic study of Islamic jurisprudence and theology. The redirection operated through the establishment of the *madrasa* system — institutionalized colleges devoted to religious-legal education — and through the consolidation of the four Sunni schools of law (*madhhab*) — the Hanafi, Maliki, Shafi'i, and Hanbali schools — as the operational framework within which subsequent Islamic legal and

theological work would be conducted.

The institutional development was anchored at specific historical moments and through specific institutional founders. The Nizamiyya colleges, founded by the Seljuq vizier Nizam al-Mulk beginning in 1065 at Baghdad and shortly thereafter at Nishapur, Isfahan, Basra, Herat, Mosul, and other major centers of the Seljuq empire, supplied the institutional infrastructure for the systematic training of religious-legal scholars. The Nizamiyya at Baghdad was, at its founding, the most heavily endowed educational institution of the period — supported by waqf endowments that supplied considerable continuing funding, staffed by senior religious scholars whose appointments carried both stipend and prestige, attended by students whose graduates received priority in the senior judicial and religious-administrative positions of the Seljuq state. The institutional model reproduced rapidly across the Islamic world. By 1200 there were several hundred madrasas operating across the broader region from al-Andalus through Egypt and the Levant to Iraq, Iran, and Central Asia. By 1500 the figure had reached several thousand. The Islamic educational infrastructure had been, in operational terms, comprehensively redirected toward religious-legal study.

The figure conventionally associated with the intellectual dimensions of this institutional redirection is Abu Hamid al-Ghazali (1058-1111), the senior religious scholar whose appointment to the Nizamiyya of Baghdad in 1091 placed him at the operational center of the new institutional system and whose subsequent published work — particularly his *Tahafut al-Falasifa* (*The Incoherence of the Philosophers*, completed approximately 1095) — supplied the most operationally consequential critique of the Aristotelian-influenced philosophical tradition that Ibn Sina and al-Farabi had developed in the previous century. The historiographical debate over al-Ghazali's specific responsibility for the subsequent decline of Islamic natural-philosophical work is unsettled and need not be settled here; recent scholarship has argued that al-Ghazali's intellectual position was considerably more nuanced than the popular account permits, and that the actual decline of natural-philosophical work proceeded across the subsequent two centuries through institutional and political mechanisms more complex than al-Ghazali's specific writings produced. The institutional point remains valid regardless of the specific intellectual attribution. The Islamic intellectual class, from approximately the twelfth century forward, was being trained through institutions whose curricular focus was religious-legal study rather than natural-philosophical work, was being employed in positions whose operational responsibilities ran toward jurisprudence and religious administration rather than toward scientific investigation, and was being recruited into a broader institutional configuration whose orientation differed markedly from what the Abbasid period had supported.

The closure of the door of *ijtihad* (independent reasoning in legal matters) — a development that historians of Islamic law have placed at approximately 1100, though the dating and the actual content of the closure remain contested in the scholarly literature — registered the institutional

consolidation. The four Sunni schools of law had reached, by approximately the twelfth century, a state of institutional maturity that the broader Islamic legal community considered to have largely exhausted the productive work of independent legal reasoning. Subsequent legal work, by the broader institutional understanding, would proceed through *taqlid* (imitation of the established positions of the four schools) rather than through independent reasoning that might challenge the established framework. The intellectual energy of successive generations of Islamic scholars was, after this consolidation, channeled into the elaboration of the established legal positions rather than into the systematic investigation of new questions in natural philosophy or the broader range of intellectual disciplines.

The structural parallel with the Chinese case is worth registering. In both civilizations, the institutional configuration that emerged across a specific historical period redirected the intellectual capacity of subsequent generations away from natural-philosophical work and toward an alternative curriculum that the institutional apparatus supported. In China the alternative curriculum was the Confucian classics and the examination system. In the post-Abbasid Islamic world the alternative was the religious-legal curriculum of the four schools of law and the madrasa system. In both cases the natural-philosophical work that the earlier periods had produced was preserved through the documentary tradition but was not extended through the institutional infrastructure that subsequent natural-philosophical development would have required. In both cases the institutional configuration produced the outcomes that its specific orientation directed it toward — bureaucratic governance in China, religious-legal scholarship in the post-Abbasid Islamic world — rather than the outcomes that a differently oriented configuration would have produced.

The English configuration's specific feature, by contrast with both Chinese and Islamic alternatives, was its orientation toward natural-philosophical work itself as the central activity that the institutional infrastructure was built to support. The Royal Society was not, in its founding self-conception, a religious or legal institution whose curriculum happened also to include some natural-philosophical work. It was specifically a natural-philosophical institution whose institutional infrastructure was built for the support of that work. The dissenting academies were not religious-legal institutions; they were broader educational institutions whose curriculum included natural-philosophical work alongside the religious and humanistic subjects. The provincial scientific societies were not bureaucratic or religious institutions; they were specifically natural-philosophical and technical-industrial institutions. The institutional orientation in the English case ran in the specific direction that the natural-philosophical work itself required, in ways the comparable Chinese and Islamic institutional configurations had not done.

IV. The European Comparisons

The comparison among the European civilizations is more nuanced than the broader civilizational comparisons because the European countries shared a common cultural and intellectual inheritance and because the institutional differences among them were differences within a broader common framework rather than differences across markedly different civilizational configurations.

France had developed, across the seventeenth and eighteenth centuries, the institutional configuration that this case's Part I touched on briefly — the Académie des Sciences, founded in 1666 under Colbert's direction with state funding, with members appointed by royal authority, with research programs directed by royal officials, with publications subject to crown approval. The French configuration produced, across the seventeenth and eighteenth centuries, an enormous body of high-quality natural-philosophical work. Huygens, Cassini, Roemer, Mariotte, Lavoisier, Laplace, Lagrange — the major figures of French natural philosophy across the period conducted their work within the institutional framework the Académie supplied. The work was operationally formidable. The French scientific apparatus was, across long periods of the eighteenth century, the European leader in mathematical mechanics, in chemistry, and in several other specific fields.

What the French configuration lacked, in comparison with the English, was the structural autonomy from political authority and the broader institutional integration with non-state institutional networks that the English configuration possessed. The Académie was a department of the French state operating under whatever political authority controlled the state at any given moment. The Revolution of 1789 produced the operational consequence the configuration's structural vulnerability had implied. The Académie was suspended in 1793. Lavoisier was guillotined in May 1794, the political authorities of the revolutionary period finding his role as a tax-farmer under the *ancien régime* sufficient justification for his execution despite his scientific eminence. The Académie was reconstituted in 1795 as a constituent body within the new Institut National, then reorganized successively across the political transformations of the following decades. The institutional continuity was preserved across the transformations through the larger French state's continuing commitment to maintaining a national scientific institution, but the continuity was preserved through state authority rather than through the institution's own self-perpetuating governance.

The French configuration also had not developed the broader institutional ecology — the provincial scientific societies, the parallel educational system, the integration with industrial work at commercial scale — that the English configuration had built. French scientific work across the eighteenth century was overwhelmingly concentrated at Paris under the Académie's institutional patronage. The provincial scientific work was operationally modest. The integration with industrial production, while present, did not approach the scale or institutional depth that the Lunar Society

and the broader provincial-society network had supplied in England. The French industrial economy of the eighteenth century — modest by the broader European measure of the period, advancing slowly across the nineteenth century but never reaching the institutional density of British industrial development — registered the consequences of the institutional difference.

The German states across the same period had produced significant natural-philosophical work but had not developed comparable institutional infrastructure at national scale. The German political configuration through 1871 was fragmented into approximately three hundred separate sovereign and semi-sovereign entities whose individual scientific institutional capacity was modest. The major German universities — Wittenberg, Leipzig, Heidelberg, Jena, Göttingen (founded 1734), Halle (founded 1694) — operated as institutional centers of theological, classical, and humanistic scholarship more than of natural-philosophical work. The Berlin Academy of Sciences, founded in 1700 under Leibniz's institutional influence with Frederick I of Prussia's patronage, operated as the principal German scientific institution but did not approach the scale or institutional density of the Royal Society. The German states' aggregate scientific institutional capacity in 1800 was significant but did not match the English configuration.

The German university reforms that emerged across the early nineteenth century — the founding of the University of Berlin in 1810 under Wilhelm von Humboldt's institutional design, the elaboration of the research-university model across the subsequent decades, the development of the laboratory-based scientific instruction that Justus von Liebig pioneered at Giessen from 1825 — would shortly produce, across the second half of the nineteenth century, the dominant research-university system in the world. The German scientific apparatus by 1900 would far exceed what the English configuration was producing. But the German transformation had not been completed by 1859. The configuration in 1859 was, in aggregate, still the English configuration at the leading edge of European scientific institutional development.

The Netherlands had produced extraordinary scientific work in the seventeenth century — Huygens at The Hague (his work on the wave theory of light, his contributions to mechanics and astronomy), the Bernoullis at Basel (a Swiss family but operating within the broader Dutch-Swiss intellectual community), Boerhaave at Leiden (his foundational work in clinical medicine), the broader range of Dutch natural philosophy that the seventeenth-century Dutch Golden Age produced. The Dutch configuration of the seventeenth century had been operationally formidable at the individual-practitioner level. What it had not developed was the broader institutional infrastructure that the English configuration would shortly build. The Dutch universities operated as significant educational institutions but not as the centers of cumulative natural-philosophical research that the seventeenth-century Royal Society was becoming. The Dutch scientific work peaked in the seventeenth century and did not sustain the institutional momentum into the eighteenth and nineteenth centuries at the scale that the English configuration achieved. The Dutch case registers, by negative example, what the English configuration had specifically supplied — the

institutional infrastructure that converted individual scientific accomplishment into a continuing collective enterprise across multiple generations.

The Italian states had produced, across the late sixteenth and early seventeenth centuries, what was at the time the most operationally consequential natural-philosophical work in Europe — Galileo's mechanics and astronomy, the broader work of the Florentine and Roman scientific circles that the early seventeenth century had supported. The Italian scientific moment was real. The institutional consequences of the Galileo trial of 1633, and of the broader Counter-Reformation institutional pressures that the Italian Catholic states maintained across the subsequent two centuries, redirected Italian intellectual life away from natural-philosophical work that might conflict with theological doctrine. The Accademia dei Lincei, which had supported Galileo's work, effectively dissolved with the death of its founder Federico Cesi in 1630. The Accademia del Cimento at Florence lasted only ten years (1657-1667) before its dissolution. The subsequent Italian institutional configuration did not produce the cumulative natural-philosophical apparatus that the English configuration was building across the same period. Italian scientific work continued at attenuated levels through the eighteenth century but did not regain the position the Galileo period had supplied.

The structural feature that the European comparisons register is the operational consequence of institutional autonomy from political and religious authority. The English configuration's specific advantage, across the European comparisons, was that the Royal Society had been built as a chartered corporation with self-perpetuating governance, operating with royal sanction but not under royal direction, supported by Fellows' subscriptions rather than by state appropriations, free to determine its own research agenda and to publish its own findings. The French configuration was a department of the state. The Italian configuration was subject to ecclesiastical constraint. The German states' configuration was fragmented across the political fragmentation of the broader German polity. The Dutch configuration had not developed beyond the personal patronage of individual practitioners. Only the English configuration had built the institutional autonomy that would shortly prove operationally decisive across the long-term cumulative development of natural-philosophical work.

V. What the Configuration Accomplished

What the English institutional configuration accomplished, by 1859, can be specified at the level of operational outcome.

It had produced the world's first industrial economy. The cotton mills of Lancashire, the iron foundries of the Black Country, the coal mines of Northumberland and South Wales, the railway network that had been built across Britain across the 1830s and 1840s, the shipbuilding yards of the Clyde and the Tyne, the broader range of industrial enterprise whose aggregate output the period's

measurements registered — all of these had been built within the institutional configuration the case has traced. The configuration's specific features had supplied the technical capacity, the financial infrastructure, the educated workforce, the patent protection, and the broader institutional support that the industrial development required. No other country had developed comparable industrial capacity by 1859. The British industrial economy in that year was much larger than the industrial economies of any other country, possibly larger than those of all other countries combined.

It had produced the world's first sustained tradition of cumulative natural-philosophical work at industrial scale. The continuous publication of *Philosophical Transactions* from 1665 to 1859 — 194 years of continuous monthly or quarterly issues, supplying the cumulative documentary record of British natural-philosophical work across nearly two centuries — was, by 1859, the longest-running scientific publication tradition in the world. The aggregate published output across all the institutional channels the configuration supplied — the Royal Society, the specialist societies, the provincial societies, the British Association, the broader publishing apparatus — was the largest scientific publication output in the world.

It had produced, across its operational period, the foundational work in mechanics (Newton), chemistry (Boyle, Priestley, Davy, Dalton, Faraday), electricity and magnetism (Faraday, with Maxwell's mathematical formalization to follow in the 1860s and 1870s), geology (Hutton, Lyell, the broader Geological Society membership), biology (Darwin, Wallace, Huxley, the broader natural-historical community), and the wider range of natural-philosophical disciplines whose specific contents had been largely shaped by British work. The intellectual content of nineteenth-century natural philosophy was largely the content that the British configuration had produced.

It had produced the cultural prestige that the previous Parts have registered as one of the structural features the configuration required. Scientific accomplishment had been integrated into the broader cultural life of educated Britain in ways that the earlier periods had not produced. The state funeral and Westminster Abbey burial of Newton in 1727 had registered the configuration's early arrival at this cultural position. The continued institutional recognition of subsequent figures — Davy's baronetcy in 1818, Faraday's repeated honors (he declined the Royal Society Presidency twice and a knighthood, but his standing was institutionally recognized through the Fullerian Professorship at the Royal Institution and the broader pattern of his public reputation), Darwin's eventual Westminster Abbey burial in 1882 — registered the continuation of the cultural pattern. Scientific work was, by the middle of the nineteenth century, an activity that the broader British cultural configuration treated as worthy of the highest national honor. Jefferson had placed Newton, Bacon, and Locke on the wall at Monticello in the 1790s because the broader Anglo-American cultural inheritance had, by that period, established these figures as the appropriate decoration of an educated gentleman's library. The cultural position the broader configuration had supplied was, by 1859, the position that scientific accomplishment occupied in the broader British cultural life.

It had produced, through the *Origin of Species* of November 1859, what would shortly become one of the most operationally consequential single intellectual works in the history of natural philosophy. The work would supply, across the subsequent century and a half, the integrative framework within which subsequent biological, paleontological, genetic, and molecular work would be conducted. The institutional configuration the case has been tracking supplied the operational conditions within which Darwin's twenty-three years of work could be conducted, communicated, and integrated into the broader scientific community. The intellectual capacity was Darwin's. The institutional infrastructure that converted the capacity into the published work was the configuration's.

The aggregate accomplishment by 1859 was the operational consequence of what the case has been tracking. The configuration had been built across approximately two hundred thirty years from Bacon's *New Atlantis* of 1627 forward. The building had been conducted by successive generations of natural philosophers, industrialists, educators, and the broader cohort of figures the previous Parts have specified. The aggregate the configuration produced exceeded what any individual builder had specifically planned. The institutional memory that the configuration carried was the cumulative product of the institutional decisions made by every generation that had operated within it. The trajectory across the two hundred thirty years was the trajectory the institutional configuration's specific features had supplied.

VI. The Close

This case has tracked the institutionalization of science in England from the publication of Bacon's *Novum Organum* in 1620 to the publication of Darwin's *Origin of Species* in November 1859. The analytical thread the case has carried through its six Parts has been the proposition Tom Bryan named at the outset — that institutional backing and institutional memory carry scientific work forward across generations in ways that no individual lifetime can accomplish, and that the specific feature of the English case is the institutional configuration that the broader civilization built to support this work.

The case has demonstrated, across its specific historical material, what the proposition requires. Newton without the Royal Society would have been a strange Cambridge professor whose papers might have survived in fragments. Newton inside the Royal Society became, through the institutional work of Halley and the broader apparatus the Society supplied, the operational center of European natural philosophy and the figure whose burial at Westminster Abbey in 1727 registered the cultural position scientific accomplishment had acquired in British public life. Watt without Boulton and the Lunar Society and the broader configuration would have been a Scottish instrument-maker whose insight into the separate condenser might or might not have produced commercial application. Watt inside the institutional configuration that the Lunar Society supplied, the patent system protected, and the City of London capital markets financed produced, across the

period from 1769 to 1800, approximately five hundred operating steam engines that supplied the mechanical power foundation of the early industrial economy. Faraday without the Royal Institution would have been a bookbinder's apprentice whose self-education in chemistry might or might not have reached the level of his actual accomplishment. Faraday inside the Royal Institution conducted, across his fifty-four years at Albemarle Street, the experimental work whose results would supply the operational foundations of nineteenth-century electrical science. Darwin without the broader configuration the case has tracked — without Wedgwood family wealth, the Geological Society, the Linnean Society, the broader correspondence network, John Murray's commercial publishing apparatus, the institutional integration that processed the Wallace priority through the joint Linnean Society publication of August 1858 — would have been a gentleman naturalist whose twenty-three years of work might or might not have produced the published *Origin* in November 1859. The intellectual capacity in each case was the necessary condition. The institutional configuration was the operational condition.

The configuration was not built by anyone in particular. It was built across two hundred thirty years through the institutional decisions of successive generations whose individual contributions accumulated into what the configuration eventually became. Bacon supplied the institutional vision in 1627. The Hartlib circle and the Wadham group supplied the operational precursors across the 1640s and 1650s. The founders of the Royal Society at the November 1660 meeting at Gresham College supplied the central institutional foundation. Boyle, Hooke, Newton, Halley, the broader cohort of the first generation supplied the work the institution captured. The dissenting communities, forced by the Restoration religious settlement to build their own educational infrastructure, supplied the parallel system that the eighteenth century would shortly require. Jennings, Doddridge, Ashworth, Belsham, Priestley, and the broader cohort of the dissenting academy tradition supplied the curricular innovations the industrial economy would shortly need. Darwin (Erasmus), Boulton, Watt, Wedgwood, the Lunar Society membership supplied the institutional model for the integration of natural-philosophical work with industrial application. Banks supplied the central institutional coordination across the apex period from 1778 to 1820. Davy and Faraday at the Royal Institution supplied the research-and-public-communication model that the early nineteenth century elaborated. Babbage, Brewster, Harcourt, the founders of the British Association supplied the institutional reform that distributed the central coordinating function. Darwin (Charles) and Wallace supplied, in 1859, what may have been the most operationally consequential single intellectual product the configuration ever produced.

No one of these figures built the configuration. Each of them contributed to what the configuration eventually became. The institutional memory the case has been tracking carried, across the two hundred thirty years of the configuration's specific development, the cumulative work of all of them. The configuration was, by 1859, the institutional inheritance of two hundred thirty years of specific decisions made by specific people at specific times. The decisions had been operationally consequential. The aggregate the decisions produced exceeded what any individual

decision had specifically planned. The trajectory was the cumulative outcome of operational decisions made by apex operators across centuries, each working at the scale of their own period and within the constraints of their own conditions. Across centuries the accumulation became what the configuration had become.

This is what institutional power does across long historical periods. It carries forward whatever the founders built, into conditions the founders did not foresee, and produces outcomes the founders did not plan. Bacon imagined Salomon's House in 1627 as the institutional vehicle through which the systematic study of nature would extend the bounds of human empire. The institutional vehicle the subsequent generations built supplied what Bacon had imagined and far more — the foundation of an industrial economy whose operational scale Bacon could not have specifically envisioned, the foundation of a sustained tradition of cumulative scientific work whose specific contents Bacon could not have specifically predicted, the foundation of a cultural configuration in which scientific accomplishment had become the natural intellectual activity of an educated person in ways the seventeenth century had not yet established. The vehicle had been built for one purpose and adapted across centuries to a series of subsequent purposes. The vehicle's specific operational features had supplied what each subsequent generation required and had been refined in light of what each subsequent generation had encountered.

The trajectory continued past 1859. The case has tracked the configuration's development to the operational moment that the *Origin* publication supplied. The subsequent development — the transformation of the configuration across the late nineteenth and twentieth centuries through the institutional pressure of the German research-university model, the professionalization of scientific work that the late nineteenth century would shortly produce, the transformation of British science from the predominantly amateur configuration of the early nineteenth century to the predominantly professional configuration of the twentieth, the broader institutional changes that the modern scientific apparatus would shortly require — is the subject for a different case rather than this one. What this case has tracked is the configuration's specific development from 1620 to 1859 — the period during which the configuration was built and during which the configuration produced what it produced.

The point Tom Bryan named at the outset is the point the case has demonstrated. Institutional backing and institutional memory carry scientific work forward across generations in ways that no individual lifetime can accomplish. The English case demonstrates, at the operational level of specific institutional development across two centuries, what this proposition requires. The configuration had been built. The configuration carried the work. The configuration produced the cumulative outcome. The intellectual capacity supplied the necessary condition. The institutional configuration supplied the operational condition. The two together produced what the two together had been built to produce.

Jefferson placed Newton, Bacon, and Locke on his wall at Monticello in the 1790s. The three men had operated within the institutional configuration the case has tracked. The figures were the visible representatives of what the configuration had supplied. The configuration was the operational mechanism through which the figures' work had reached Jefferson's library, and through which the figures' standing had been established as the appropriate decoration of an educated gentleman's space. The figures and the configuration were inseparable. The figures could not have done what they did without the configuration. The configuration could not have produced what it produced without the figures. The two together — the figures and the configuration — supplied what the broader civilizational development required.

The case ends at the *Origin* of November 1859 because that is where its analytical question reaches its operational resolution. The institutional configuration the case has been tracking had, by 1859, accomplished what it had been built to accomplish. The configuration would continue, with subsequent modifications, across the following century and a half. What it had produced by 1859 was what this case has set out to register.

Bibliography

Primary Sources

Babbage, Charles. *Reflections on the Decline of Science in England, and on Some of its Causes*. London: B. Fellowes, 1830.

Bacon, Francis. *Novum Organum*. London: John Bill, 1620.

———. *The New Atlantis*. Published with *Sylva Sylvarum*. London: William Lee, 1627.

———. *The Advancement of Learning*. London: Henrie Tomes, 1605.

Banks, Joseph. *The Endeavour Journal of Joseph Banks, 1768–1771*, ed. J. C. Beaglehole. 2 vols. Sydney: Angus and Robertson, 1962.

Boyle, Robert. *The Sceptical Chymist*. London: J. Cadwell, 1661.

———. *New Experiments Physico-Mechanicall, Touching the Spring of the Air, and its Effects*. Oxford: H. Hall, 1660.

———. *The Correspondence of Robert Boyle*, ed. Michael Hunter, Antonio Clericuzio, and Lawrence M. Principe. 6 vols. London: Pickering & Chatto, 2001.

Darwin, Charles. *On the Origin of Species by Means of Natural Selection*. London: John Murray, 1859.

———. *Journal of Researches into the Geology and Natural History of the Various Countries Visited by H.M.S. Beagle*. London: Henry Colburn, 1839.

———. *The Correspondence of Charles Darwin*, ed. Frederick Burkhardt et al. 30 vols. Cambridge: Cambridge University Press, 1985–2023.

Davy, Humphry. *Elements of Chemical Philosophy*. London: J. Johnson, 1812.

Faraday, Michael. *Experimental Researches in Electricity*. 3 vols. London: Bernard Quaritch, 1839–1855.

———. *The Correspondence of Michael Faraday*, ed. Frank A. J. L. James. 6 vols. London: Institution of Engineering and Technology, 1991–2012.

Hartlib, Samuel. *Samuel Hartlib and the Advancement of Learning*, ed. Charles Webster. Cambridge: Cambridge University Press, 1970.

Hooke, Robert. *Micrographia: or Some Physiological Descriptions of Minute Bodies Made by Magnifying Glasses*. London: Royal Society, 1665.

Newton, Isaac. *Philosophiae Naturalis Principia Mathematica*. London: Royal Society, 1687.

———. *Opticks*. London: Sam Smith and Benj. Walford, 1704.

———. *The Correspondence of Isaac Newton*, ed. H. W. Turnbull, J. F. Scott, A. R. Hall, and Laura Tilling. 7 vols. Cambridge: Cambridge University Press, 1959–1977.

Oldenburg, Henry. *The Correspondence of Henry Oldenburg*, ed. A. Rupert Hall and Marie Boas Hall. 13 vols. Madison: University of Wisconsin Press; London: Mansell; London: Taylor & Francis, 1965–1986.

Philosophical Transactions of the Royal Society of London. London: Royal Society, 1665–present.

Priestley, Joseph. *An Essay on a Course of Liberal Education for Civil and Active Life*. London: C. Henderson, 1765.

———. *The History and Present State of Electricity, with Original Experiments*. London: J. Dodsley, 1767.

———. *Experiments and Observations on Different Kinds of Air*. 3 vols. London: J. Johnson, 1774–1777.

Royal Society Journal Book. Royal Society Archives, London.

Royal Society Charter, July 15, 1662. Royal Society Archives, London.

Sprat, Thomas. *The History of the Royal Society of London, for the Improving of Natural Knowledge*. London: J. Martyn and J. Allestry, 1667.

Wallace, Alfred Russel. *Contributions to the Theory of Natural Selection*. London: Macmillan, 1870.

Watt, James. *Patent Specification No. 913: A New Invented Method of Lessening the Consumption of Steam and Fuel in Fire Engines*, January 5, 1769.

Wedgwood, Josiah, and Joseph Priestley. *Selected Correspondence*, in *The Letters of Josiah Wedgwood*, ed. Katherine Eufemia Farrer. 3 vols. Manchester: E. J. Morten, 1903–1906.

Statutes and Foundational Documents

Act of Uniformity, 1662. 14 Charles II, c. 4. *Statutes of the Realm*, vol. 5.

Conventicle Act, 1664. 16 Charles II, c. 4. *Statutes of the Realm*, vol. 5.

Five Mile Act, 1665. 17 Charles II, c. 2. *Statutes of the Realm*, vol. 5.

Test Act, 1673. 25 Charles II, c. 2. *Statutes of the Realm*, vol. 5.

Toleration Act, 1689. 1 William & Mary, c. 18. *Statutes of the Realm*, vol. 6.

Statute of Monopolies, 1624. 21 James I, c. 3. *Statutes of the Realm*, vol. 4.

Steam Engine Act, 1775. 15 George III, c. 61. *Statutes at Large*.

Patent Law Amendment Act, 1852. 15 & 16 Victoria, c. 83. *Statutes of the Realm*.

University Tests Act, 1854 (Oxford). 17 & 18 Victoria, c. 81.

University Tests Act, 1856 (Cambridge). 19 & 20 Victoria, c. 88.

Universities Tests Act, 1871. 34 & 35 Victoria, c. 26.

Secondary Sources

Allan, D. G. C. *William Shipley: Founder of the Royal Society of Arts*. London: Hutchinson, 1979.

Andrade, E. N. da C. *A Brief History of the Royal Society*. London: Royal Society, 1960.

Berman, Morris. *Social Change and Scientific Organization: The Royal Institution, 1799–1844*. Ithaca: Cornell University Press, 1978.

Browne, Janet. *Charles Darwin: Voyaging*. New York: Knopf, 1995.

———. *Charles Darwin: The Power of Place*. New York: Knopf, 2002.

Cohen, I. Bernard. *Introduction to Newton's "Principia"*. Cambridge, Mass.: Harvard University Press, 1971.

Crosland, Maurice. *Scientific Institutions and Practice in France and Britain, c. 1700–c. 1870*. Aldershot: Variorum, 1992.

Desmond, Adrian, and James Moore. *Darwin: The Life of a Tormented Evolutionist*. New York: Warner Books, 1991.

Forbes, R. J. *The Conquest of Nature: Technology and its Consequences*. New York: New American Library, 1968.

Geikie, Archibald. *Annals of the Royal Society Club*. London: Macmillan, 1917.

Gillispie, Charles Coulston. *Science and Polity in France: The End of the Old Regime*. Princeton: Princeton University Press, 1980.

Gleick, James. *Isaac Newton*. New York: Pantheon, 2003.

Glick, Thomas F. *The Comparative Reception of Darwinism*. Chicago: University of Chicago Press, 1988.

Hahn, Roger. *The Anatomy of a Scientific Institution: The Paris Academy of Sciences, 1666–1803*. Berkeley: University of California Press, 1971.

Hall, A. Rupert. *The Revolution in Science, 1500–1750*. London: Longman, 1983.

Hall, Marie Boas. *Promoting Experimental Learning: Experiment and the Royal Society, 1660–1727*. Cambridge: Cambridge University Press, 1991.

Hans, Nicholas. *New Trends in Education in the Eighteenth Century*. London: Routledge & Kegan Paul, 1951.

Heilbron, J. L. *Electricity in the Seventeenth and Eighteenth Centuries: A Study of Early Modern Physics*. Berkeley: University of California Press, 1979.

———. *The Sun in the Church: Cathedrals as Solar Observatories*. Cambridge, Mass.: Harvard University Press, 1999.

Hodgson, Marshall G. S. *The Venture of Islam: Conscience and History in a World Civilization*. 3 vols. Chicago: University of Chicago Press, 1974.

Hunter, Michael. *Establishing the New Science: The Experience of the Early Royal Society*. Woodbridge: Boydell Press, 1989.

———. *The Royal Society and Its Fellows, 1660–1700: The Morphology of an Early Scientific Institution*. Chalfont St. Giles: British Society for the History of Science, 1982.

———. *Boyle: Between God and Science*. New Haven: Yale University Press, 2009.

Iliffe, Rob. *Priest of Nature: The Religious Worlds of Isaac Newton*. Oxford: Oxford University Press, 2017.

James, Frank A. J. L. *Michael Faraday: A Very Short Introduction*. Oxford: Oxford University Press, 2010.

———, ed. *The Correspondence of Michael Faraday*. 6 vols. London: Institution of Engineering and Technology, 1991–2012.

Jardine, Lisa. *Ingenious Pursuits: Building the Scientific Revolution*. London: Little, Brown, 1999.

———. *The Curious Life of Robert Hooke: The Man Who Measured London*. London: HarperCollins, 2003.

Kelly, Thomas. *George Birkbeck: Pioneer of Adult Education*. Liverpool: Liverpool University Press, 1957.

Knight, David. *Humphry Davy: Science and Power*. Cambridge: Cambridge University Press, 1992.

Lapidus, Ira M. *A History of Islamic Societies*. 2nd ed. Cambridge: Cambridge University Press, 2002.

MacLeod, Christine. *Inventing the Industrial Revolution: The English Patent System, 1660–1800*. Cambridge: Cambridge University Press, 1988.

Makdisi, George. *The Rise of Colleges: Institutions of Learning in Islam and the West*. Edinburgh: Edinburgh University Press, 1981.

McLachlan, Herbert. *English Education under the Test Acts: Being the History of the Nonconformist Academies, 1662–1820*. Manchester: Manchester University Press, 1931.

Mokyr, Joel. *The Gifts of Athena: Historical Origins of the Knowledge Economy*. Princeton: Princeton University Press, 2002.

———. *The Enlightened Economy: An Economic History of Britain, 1700–1850*. New Haven: Yale University Press, 2009.

Morrell, Jack, and Arnold Thackray. *Gentlemen of Science: Early Years of the British Association for the Advancement of Science*. Oxford: Clarendon Press, 1981.

Needham, Joseph. *Science and Civilisation in China*. Multi-volume series, with various collaborators. Cambridge: Cambridge University Press, 1954–present.

———. *The Grand Titration: Science and Society in East and West*. London: Allen & Unwin, 1969.

Nuttall, Geoffrey F. *Visible Saints: The Congregational Way, 1640–1660*. Oxford: Blackwell, 1957.

Porter, Roy. *Enlightenment: Britain and the Creation of the Modern World*. London: Allen Lane, 2000.

———. *The Making of Geology: Earth Science in Britain, 1660–1815*. Cambridge: Cambridge University Press, 1977.

Robinson, Eric, and Douglas McKie, eds. *Partners in Science: Letters of James Watt and Joseph Black*. London: Constable, 1970.

Roy, Marie-Andrée Bertrand. *L'Académie royale des sciences, 1666–1793*. Paris: Hermann, 1979.

Rule, John. *The Vital Century: England's Developing Economy, 1714–1815*. London: Longman, 1992.

Rupke, Nicolaas A. *The Great Chain of History: William Buckland and the English School of Geology, 1814–1849*. Oxford: Clarendon Press, 1983.

Schaffer, Simon. *Mechanical Babbage and the Royal Astronomical Society*, in *Cultural Babbage: Technology, Time and Invention*, ed. Francis Spufford and Jenny Uglow. London: Faber & Faber, 1996.

Schofield, Robert E. *The Lunar Society of Birmingham: A Social History of Provincial Science and Industry in Eighteenth-Century England*. Oxford: Clarendon Press, 1963.

———. *The Enlightenment of Joseph Priestley: A Study of His Life and Work from 1733 to 1773*. University Park: Pennsylvania State University Press, 1997.

Shapin, Steven. *A Social History of Truth: Civility and Science in Seventeenth-Century England*. Chicago: University of Chicago Press, 1994.

Shapin, Steven, and Simon Schaffer. *Leviathan and the Air-Pump: Hobbes, Boyle, and the Experimental Life*. Princeton: Princeton University Press, 1985.

Smith, Crosbie, and M. Norton Wise. *Energy and Empire: A Biographical Study of Lord Kelvin*. Cambridge: Cambridge University Press, 1989.

Stewart, Larry. *The Rise of Public Science: Rhetoric, Technology, and Natural Philosophy in Newtonian Britain, 1660–1750*. Cambridge: Cambridge University Press, 1992.

Sutherland, L. S., and L. G. Mitchell, eds. *The History of the University of Oxford*, vol. 5: *The Eighteenth Century*. Oxford: Clarendon Press, 1986.

Thackray, Arnold. *Natural Knowledge in Cultural Context: The Manchester Model*. *American Historical Review* 79 (1974): 672–709.

Thomas, John Meurig. *Michael Faraday and the Royal Institution: The Genius of Man and Place*. Bristol: Hilger, 1991.

Uglow, Jenny. *The Lunar Men: Five Friends Whose Curiosity Changed the World*. London: Faber & Faber, 2002.

Webster, Charles. *The Great Instauration: Science, Medicine and Reform, 1626–1660*. London: Duckworth, 1975.

———, ed. *Samuel Hartlib and the Advancement of Learning*. Cambridge: Cambridge University Press, 1970.

Westfall, Richard S. *Never at Rest: A Biography of Isaac Newton*. Cambridge: Cambridge University Press, 1980.

———. *The Construction of Modern Science: Mechanisms and Mechanics*. Cambridge: Cambridge University Press, 1971.

Williams, L. Pearce. *Michael Faraday: A Biography*. New York: Basic Books, 1965.

Wykes, David L. *To Revive the Memory of Some Excellent Men: Edmund Calamy and the Early Historians of Nonconformity*. London: Dr Williams's Trust, 1997.